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CONTENTS

IGR TRANSLITERATION OF RUSSIAN

The AGI Translation Center has adopted the essential features of Cyrillic Transliteration recommended by the U. S. Department of the Interior, Board of Geographical Names, Washington, D. C.

Alphabet		transliteration
А	а	a
Б	б	b
В	в	v
Г	г	g
Д	д	d
Е	е	e, ye (1)
Ё	ё	ë, yë
Ж	ж	zh
З	з	z
И	и	i (2)
Й	й	y
К	к	k
Л	л	l
М	м	m
Н	н	n
О	о	o
П	п	p
Р	р	r
С	с	s
Т	т	t
У	у	u
Ф	ф	f
Х	х	kh
Ц	ц	ts
Ч	ч	ch
Ш	ш	sh
Щ	щ	shch
Ъ	ъ	" (3)
Ы	ы	y
Ь	ь	' (3)
Э	э	e
Ю	ю	yu
Я	я	ya

However, the AGI Translation Center recommends the following modifications:

1. Ye initially, after vowels, and after ъ, ь. Customary usage calls for "ie" in many names, e.g., SOVIET KIEV, DNIEPER, etc.; or "ye", e.g., BYELORUSSIA, where "e" follows consonants. "e" with dieresis in Russian should be given as "yo".

2. Omitted if preceding a y, e.g., Arkhangelsky (not iy; not ii).

3. Generally omitted.

NOTE: The well-known place and personnel names that have wide acceptance in international literature will be here adopted. However, German-type transliteration e.g., J for Y will not be used.

CERTAIN DATA ON THE GENESIS AND ECOLOGIC CHARACTER OF FRASNIAN REEFS OF THE ARDENNES [1]

by
Marius Lecompte
• translated by P. F. Moore •

ABSTRACT

The confinement of origin and development of modern coral reefs to the zone of turbulence is apparently linked to the symbiosis of corals and zooxanthellids. The Frasnian (Devonian) reefs of the Ardennes (Belgium) were constructed by stromatoporoids or corals, with associated marine forms. Reefs formed of massive stromatoporoids developed in the zone of turbulence; coral reefs were constructed beneath this zone; and mixed reefs either started in one environment and shifted to another or developed in an intermediate zone. To each one of these environmental conditions there corresponds a particular morphologic structural type. -- G. E. Denegar.

INTRODUCTION

During the last century, the nature and genesis of Paleozoic limestones constructed by corals and stromatoporoids have received considable attention. Many authors, including myself in 1938, have noted the necessity of describing these structures ecologically to obtain useful comparisons among them.

Before attempting a synthesis or before proposing any general conclusions, it is desirable to summarize certain regional observations and to describe a certain number of carefully studied types, which I have undertaken for the Devonian structures of the Ardennes. This preliminary note is a collection of observations and considerations which might influence the direction of future research. Although it unravels the essential traits of these particular biotopes and allows certain conclusions to be drawn, it does not yet present an adequate analysis. A number of important problems, such as dolomitization, buildup, nature and color of argillaceous "terraces" interfingered with calcareous lenses in their margins, pigmentation of limestone, mechanical deformation of limestone, and so forth, are still under study. However incomplete this work may be at the present time, it gives me great pleasure to present these results in honor of the jubilee of Professor Victor Van Straelen who, when I came to the Institute 20 years ago, drew my attention to the Devonian reefs of the Ardennes and has never ceased to encourage and help me in many ways to pursue this study, making use of the knowledge of ancient and modern environments.

It is superfluous to insist on abandoning the concept which necessarily links the name "reef" to all constructed limestone masses, even if they are composed of corals. The term "coral reef" is, at present, applied to those well-defined limestone masses constructed by corals which essentially control them. The corals are associated with algae, foraminifers, sponges, hydrozoans, alcyonarians, bryozoans, mollusks, echinoderms, and other marine life which together form a marine environment of extraordinary fecundity. The special character of these structures is due to their growth at very shallow depth in the zone of intense wave action and to their buildup, in the old age, to the low-tide level which leads eventually to the emergence of debris, accumulated and sorted under the influence of marine and eolian currents. These conditions determine both the horizontal zonation which is so characteristic of reefs and their lateral expansion during old age.

The circumstances which, at present, control coral reefs and confine their origin and development to the zone of turbulence are apparently related to the symbiosis of corals and zooxanthellids, a phenomenon which is possibly of recent geologic origin. Ancient corals may not always have been subjected to the same conditions and, therefore, limestone structures resulting from coral secretory activity may have differed ecologically from modern reefs. These considerations require greater flexibility in the terminology of constructed masses.

Many masses of constructed limestone traditionally regarded as reefs have been known for a long time in the Devonian of the Ardennes. The best known are those of middle Frasnian age. These were first studied by Édouard Dupont,

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[1] Translated from Quelques données relatives à la genèse et aux caractères écologiques des "récifs" du Frasnien de l'Ardenne: (In: Brussels, L'Institut Royal des Sciences Naturelles de Belgique. Victor Van Straelen, Directeur. . . 1925-1954. Volume Jubilaire I: p. 153-194, Brussels, 1954).

former director of the Royal Museum of Natural History of Belgium, during the period from 1881 to 1892. Later, from 1907 to 1932, Fernand Delhaye produced a remarkable series of papers on these reefs. Eugène Maillieux, from 1902 to 1926, also studied them. But the reefs are also present in the Couvinian and in the Givetian.

The "reefs" of the middle Frasnian are only developed on the southern border of the Dinant basin. Plate I shows their distribution in a limited portion of the basin between Aublain and Couvin where they are particularly conspicuous in the topography along the southern border of the Plateau des Hautes Fagnes. They occur at three stratigraphic horizons labelled F2d, F2h, and F2j [36]. In many places they are superposed as figured in plate II and plate VI, figures 1 and 5.

"REEFS" OF RED MARBLE FROM F2j

The "reefs" of the upper level of the middle Frasnian are poorly developed on the southern border of the Dinant basin (plate VI, fig. 2). They are better developed farther north in the Philippeville massif where they have been exploited for marble of a predominantly red color. The method of exploitation along the grain exposes fine sections which lend themselves very well to a detailed study of their constituents. The following descriptions are drawn from the Philippeville massif.

Morphology

The reefs are small subhemispherical lenses about 100 meters (m) in diameter at base (130 m maximum) and less than 75 m high.

They consist of successive caps whose growth has been more rapid in the center. No lateral expansion is observed at the summit of any phase of their vertical development, a phenomenon which certainly would be observed if these structures had been developed in a zone of strong turbulence and had terminated at low-tide level.

These "reefs" are isolated in shales. The shale contact is sharply oblique to the reef flanks whose slopes range from 35° to 60° and may be even steeper baseward. Even on such steep flanks, constructing organisms are found in growth position with their bases conforming to reef slope. "Reef" summits never show erosion surfaces or signs of death of the coral colony. No formations which could be considered as talus are observed between the constructed limestone lens and the surrounding shales. Indications of wind- and marine-current influence in the form of elongation, which would be present if the "reefs" had formed in a zone of turbulence, are absent. The simple morphology suggests development in a calm environment. There is no present-day equivalent, except, perhaps, the knolls recently found in atollic lagoons, but these occur in obviously very different environments. The height of certain lenses (75 m) which, if the environment were stable, should show evidence from the base to the summit of progressively variable conditions of turbulence, suggests, as does their progressive narrowing towards the top, that they must have developed under conditions of subsidence.

Vertical and Constructive Development

These accumulations of largely coralline skeletons preserved in growth position indicate an exuberance of life similar to that of modern reefs to which they have been generally compared, although they lack the ecological characteristics of the latter. The richness of these Frasnian accumulations is somewhat an illusion, for the variation of the fauna has essentially a vertical character. Each successive zone, while rich in

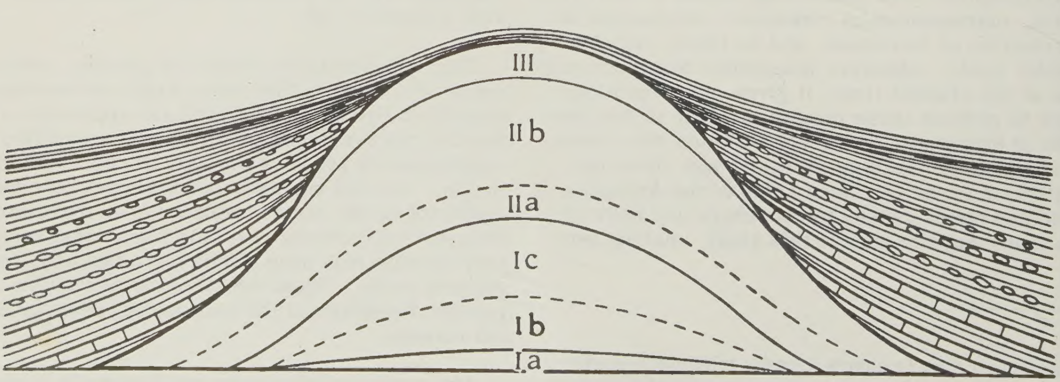


FIGURE 1. Diagrammatic cross section of a "reef" of red marble (F2j) in the Philippeville massif

individuals, is rather uniform.

The constructed limestone lenses in the Philippeville massif show evidence of vertical development in three successive phases of unequal relative importance from one reef to another (fig. 1). The first phase (fig. 1, I; plate III, figs. 1 and 2), which is very important, consists of limestone with a fine red groundmass having a more or less closely banded structure due either to lamellar corals or to a growth of calcite called Stromatactis. The phase generally begins with a very impure argillaceous limestone with intercalated shales (fig. 1, Ia) which rapidly passes into a limestone-marble characterized by an abundance of Acervularia (The forms generally called Acervularia do not really belong to this genus which is probably restricted to the Silurian, but the revision of the genus has not yet been made.) and of Alveolites, generally a single species having a small form and remarkably constant lamellar habitus aligned in growth position conformable with the hemispherical zonations of the lens (fig. 1, Ib). Other organisms are associated with these constructors. Rare Receptaculites, rare brachiopods, and small solitary rugose corals are abundant in certain traverses. In a vertical section of the "reef," Stromatactis, which characterizes the upper part of this phase (fig. 1, Ic), appear at the base as more or less rectilinear flowers of calcite and in the upper part as heavily laced and digitated forms (plate V, figs. 3, 4, 5, and 6) generally concordant with "reef" zones. Dupont, who first described and named them, regarded them as stromatoporoids [12, p. 268; 13, p. 93 and 135]. Until now, no organic structures which justify this interpretation have been found. Nevertheless, their morphologic and stratigraphic stability presupposes an organic origin.

In an earlier publication [22], following the discovery in the Bergonry quarry of numerous branches of tabulate corals included in a large mass of Stromatactis, I advanced the hypothesis that these structures could have been the result of precipitation of calcium carbonate engendered by the decomposition of organisms, apparently algal in nature. This hypothesis has been supported by new observations of J. Bellière [1] in a study of the Niagaran reefs in the region of the American Great Lakes; H. A. Lowenstam [27] has discussed the nature of these "lacy frame builders" to which he attributes major importance in raising the reef framework, in cementing of debris, and in trapping sediments. It is certain that they played an important and apparently active part in the buildup of Frasnian reefal masses because much of the lenses are almost entirely composed of these organisms. But, it would be very dangerous to use structures whose origin is still problematic to build and substantiate hypotheses of the genesis and ecologic character of the masses which contain them.

At first, Stromatactis are small and simple (plate V, figs. 3 and 4). They then begin to grow rapidly and anastomose in an irregularly meshed network (plate V, figs. 5 and 6). They are associated with lamellar colonies of Alveolites, whose abundance varies from one zone to another, and with brachiopods (particularly Gypidula), generally few in number but which may locally constitute a characteristic horizon. In their most typical zone, with large robust meshwork, they can be practically the only constucting organisms present, the Alveolites almost entirely absent. Towards the top, their density may diminish, while, at the same time, they tend to be solitary forms. Here, they are associated with numerous lamellar Alveolites, and a few Acervularia, some small rugose corals, and branching tabulate corals (particularly Cladopora), thus reconstituting the coralline facies of the base (plate V, fig. 5). In such cases, towards the top, the Alveolites colonies, while still small in size, may take on a globular habitus which presages the passage to phase II.

In phase I, the fine groundmass is composed essentially of a hash of bryozoa, admixed with ostracods, spicules, foraminifers, and minute shells. Crinoid ossicles are fairly abundant but are small in size (1 to 3 mm in diameter) and are concentrated along numerous argillaceous joints (called "terraces" by quarrymen) which are stylolitic and which generally cut the limestone in conformity with the zonation in a rather disordered network. These red and green "terraces" have no obvious relationship to the environment and pose problems far from being solved. It is not uncommon to observe them cutting Stromatactis (plate V, fig. 6), corals (which they seem to corrode), and other smaller organisms. But their complex disordered character rules out the possibility of their being argillaceous deposits on erosion surfaces.

The petrographic character and the lamellar habit and paucity of species of constructing organisms, as well as their occurrence in growth position even on the very steep flanks of the reef, indicate that this phase was raised in calm clay-laden water not conducive to the development of corals. If the occasional Alveolites raised itself from the bottom, it was so narrow (one observed was 40 cm high and a few centimeters wide) that it only serves to reinforce the same conclusion.

The second phase (fig. 1, II; plate III, figs. 1 and 2), whose thickness may be greater than the first, is characterized by a progressive loss of color (the limestone changes to a rather light pink or even to gray) and by a very noticeable increase in the proportion of cement to constructive organisms. The corals, which are more scattered and more irregularly distributed, generally no longer determine the rock banding, are frequently subglobular, remain small, and may be overturned. Brachiopods are much more abundant than in the first phase. In some zones

they even play a predominant part. Some brachiopods are disarticulated. Crinoids, too, are more abundant. Locally, the rock loses its constructed aspect.

The second phase generally begins with a Receptaculites zone (fig. 1, IIa; plate V, fig. 7 and 9) whose colonies may be 50 cm wide. Receptaculites are locally predominant; in places, they yield to large Heliophyllum helianthoides associated with small but globular Alveolites, some Acervularia, sparse brachiopods, Cladopora, small solitary and rather abundant rugose corals, and dispersed algal forms of the type Sphaerocodium, and crinoids.

The overlying limestone (fig. 1, IIb; plate V, fig. 8) is subject to more variation. At Croisettes reef, Philippeville (plate III, fig. 2), the rock is banded, due to a relative abundance of lamellar corals; at Grands Fonds quarry, Vodecée (plate III, fig. 2), the limestone is hardly constructive in appearance, particularly in the upper part where the corals are subglobular. Crinoids and brachiopods are present in greater quantity, and branching polyps such as Cladopora, Thamnopora, and Alveolites are abundantly represented. Gastropods, algae, and small solitary rugose corals are also found but in accessory quantities. It is in this zone, a short distance form the top and towards the margin of the of the least constructed-looking part, that a few lamellar stromatoporoids were observed in the Bergonry quarry. Their occurrence is remarkably rare in the F2j "reefs" and apparently they only occur as lamellar forms.

The groundmass, which is always abundant, is coarser and contains recognizable coral fragments. The granulometric characteristics are often influenced by a great abundance of crinoids which are always more concentrated along the "terraces." The fine sediment is composed of spicules, bryozoan fragments, small whole shells, and small crinoid ossicles which are neither broken nor rolled. The groundmass contains little debris from the constructing organisms; it never appears in the form of a sand with rounded grains, although towards the top it may be very crinoidal. The argillaceous and stylolitic "terraces" are mostly green, particularly towards the top.

Generally, this phase is less rich in organic remains. The corals are partly subglobular; the growth of the reefal lens in the center is more marked. These characteristics, as well as the type of cement, the disarticulation of brachiopods, the overturning of some coral colonies, and the local occurrence of stromatoporoids, indicate that wave action was felt more strongly than in the earlier phase and that less mud was deposited. The greater number of small lamellar colonies are still in place and the reef seems to have contracted, rather than expanded, laterally, which indicates that the environment of development in this period was not typical of the turbulent zone. It is certain that in this phase of its history, the reef did not reach the water surface because killed colonies of organisms and surfaces of abrasion are not present.

The last phase (fig. 1, III) with red groundmass is only a few meters thick. It may be or may not be present. It is generally only a recurrence of the initial phase, all characters of which it possesses. Locally it is represented by a crinoidal limestone which contains few other fossils (plate III, fig. 1). It marks the subsidence of the limestone lenses after a period of stability.

The margins of each of these zones are less pure than their central parts, even in the favorable phases. Argillaceous "terraces" are more frequent and more important. They diminish progressively toward the center, which demonstrates the influence of the surrounding sedimentation on the "reef." No detrital talus onto which the coralline mass might have to spread out was observed in the central and deepest phase. Nor were great concentrations of sandy material observed. The study of thin sections does not show any granulometric sorting.

More constructing organisms have been found in growth position, even on the steeper lower flanks, indicating a calm medium. If the upper part of the medial phase shows some small overturned colonies, implying mechanical wave action or currents of greater strength than existed in the earlier phase (but still much weaker than in the F2h "reefs"), it does not necessarily mean that these colonies were developed in the zone of intense wave agitation in which corals would have prospered. The constructing organisms obviously did not exist in an environment favorable for their expansion; the same species of Alveolites which, in the F2j reefs, are only found as modest lamellar colonies, form much larger colonies in the F2h reefs (I have seen some 1 m across and over 50 cm high - these are accompanied by equally important colonies of Hexagonaria). Stromatoporoids, large and frequent in the F2h reefs, are rare and always present as thin lamellae in the F2j lenses. This also indicates a rather unfavorable environment. The stromatoporoids are found only in those parts of the reef which were obviously constructed in the shallowest waters. If the various conditions observed in outcrops are considered, stromatoporoids appear to be far less resistant to an invasion of mud than tabulates and tetracorals. The massive corallines, although puny, are frequently associated with small solitary corals with some fasciculate colonies whose characteristic environment does not include shallow water. The poverty in species lends further support to this conclusion.

These reefs, however, also contain blue-green algae such as Sphaerocodium and Girvanella, which are generally considered to be indicators

of shallow water. These algae play an insignificant role and, so far, I have found them in the reef's medial phase which developed in the shallowest water. Little is known on the bathymetric distribution of these algae. In one outcrop (at Bergonry), they are found associated with numerous little solitary rugose corals and with very thin lamellar Alveolites which do not indicate a specially agitated environment in host black pyritic shales. Spaerocodium, which formed nodules analogous to those of present-day Lithothamnium (as is the case in the Silurian of Gothland), probably would have formed nodules if the reef had developed, like modern reefs, in shallow water. Adaptation of various constructing organsims to the environment only takes place vertically. Horizontal ecologic localization or particular structures which might indicate proximity to the surface or the influence of currents have not been found.

The analysis of the F2j "reefs" also indicates that these curious coralline constructions developed in a calm environment which was very different from that in which modern reefs flourish. The ancient reefs developed during the course of a fairly long period of stabilization of the sea floor. During phase II, they reached the zone of turbulence. A rather sharp subsidence reintroduced the initial facies and put a rapid end to the development of constructed limestones. The drowning was more rapid south of the Philippeville region, on the southern border of the Dinant basin, where the F2j reefs are much less strongly developed.

A study of the phenomenon of dolomitization would undoubtedly allow detailing of bathymetric conditions of the genesis of these "reefs." Dolomite has been recognized only in small scattered pockets, especially in the meshwork of the Stromatactis zones and a little less abundantly in the upper part of the medial and shallowest zones. On a regional basis at least, the F2h "reefs" are more dolomitized. Recent studies indicate that present-day dolomitization takes place only in marine waters at a very shallow depth (between 0 and 35 m) and at an elevated temperature.

The Substratum

These coralline lenses do not spread our directly over the crests of the F2h stromatoporoid "reefs," as would be expected if, as it has been supposed, the coralline lenses were developed in a shallower environment than the "reefs" and if they had an origin analogous to that of present-day reefs. If they had, the last phases of the F2h limestone masses would have made excellent preparation by creating an environment favorable for coralline growth.

At Boussu-en-Fagne, at the crest of the F2h reef, shales, rich in large polyps which may either be in growth position or overturned (Alveolites, Acervularia, and Hexagonaria), occur. To some extent, these corals continue the F2h reef but in an environment which had radically changed as a consequence of subsidence and from which all forms such as massive stromatoporoids sensitive to argillaceous deposition have been sharply eliminated. Branching tabulate corals such as Alveolites and Thamnopora were abundant after environment change; brachiopods, a few solitary rugose corals, and some lamellar stromatoporoids also occur. The subsidence is marked by the disappearance of the coralline fauna which gives way first to accumulations of Atrypa (almost exclusively), then to sparsely fossiliferous shales intercalated with thin beds of fine-grained limestone which is impure, locally nodular, and also poorly fossiliferous with some crinoids and brachiopods. The reappearance of branching tabulate corals indicates relative improvement in environmental conditions, resulting in the development of the upper (F2j) coral reefs, but not in the development of the stromatoporoid reefs for which the bathymetric conditions remained too deep.

Detailed variation of the environments of the two reefs F2h and F2j at Boussu-en-Fagne are, from the base upward:

1. Greenish, crinoidal, calcareous shale, rather fine grained, with nodules of clear calcite. Branching and massive Alveolites, Hexagonaria hexagona, Thamnopora bolonensis, Thamnopora reticulata, Thamnopora gosseleti, Acervularia, solitary rugose corals . . . 1.00 m
2. Argillaceous, earthy shale with a few limestone nodules. Branching and lamellar Alveolites, Thamnopora, solitary rugose corals, Hypothyridina cuboides, Aulacella eifeliensis, long crinoid stems, Stromatoporella sp. . . . . 0.95 m
3. Fine-grained green shale with flattened nodules of fine-grained green limestone. Rare brachiopods and long crinoid stems . . . 0.47 m
4. Two types of shale, both with flattened limestone nodules. The first: coarse-grained, crinoidal, crystalline; the second: green, fine-grained, argillaceous. Thamnopora, solitary rugose corals, Hexagonaria hexagona, Acervularia, lamellar stromatoporoids (Stromatoporella sp.), Athyris, sparse Atrypa, crinoid stems . . . . 2.80 m
5. Shale with very abundant flattened nodules aligned and pressed together; composed of bluish-gray or green, fine- or coarse-grained crinoidal sediment. Very abundant Atrypa and rare branching Alveolites . . . . 1.10 m
6. Fine-grained green shale with isolated flattened nodules of fine-grained greenish limestone. Atrypa and a few Athyris, crinoid stems . . . . 0.80 m
7. Series of limestone beds with a heterogeneous paste separated by partings of fine-grained shale. Abundant Cladopora gracilis, rare brachiopods . . . . 1.20 m
8. Coarse-grained calcareous shale interstratified with thin beds of bluish-gray semigranular crinoidal limestone. Cladopora

gracilis, Atrypa, crinoid stems . . . . . 0.95 m

9. Fine-grained shale altered to brown, with large flattened nodules of bluish-gray crinoidal limestone. Atrypa . . . . 0.80 m

10. Coarser grained calcareous shale interstratified with beds of fine-grained greenish limestone with a reddish zonation. Atrypa and long crinoid stems . . . . 1.45 m

11. Coarse-grained calcareous shale with aligned nodules of greenish, fine-grained, argillaceous, earthy limestone. Few Thamnopora, few Atrypa, scattered crinoid stems . . .1.10 m

12. Coarse-grained calcareous shale with thicker beds of nodular, greenish-gray, argillaceous, fine-grained earthy limestone. One thin intercalated bed composed of very crinoidal limestone. Atrypa and crinoid stems . . 0.50 m

13. Limy shale with flattened nodules of green crinoidal limestone comprising a rather small proportion of the rock. Rather abundant Atrypa, Thamnopora, a few branching Alveolites, long crinoid stems . . . . 3.60 m

14. Calcareous shale with isolated flattened limestone nodules and interstratified lenticular beds of limestone. The limestone is green, fine grained with coarser bluish-gray crinoidal pockets. Atrypa, Thamnopora, branching Alveolites, crinoid stems . . . . .1.20 m

15. Fine-grained, greenish, crinoidal, earthy limestone with reddish zonation. The limestone beds are separated by thin partings of coarse-grained calcareous shale. Atrypa, Hexagonaria hexagona, scarce crinoid stems . . . . . .3.20 m

16. Calcareous shale with flattened nodules of fine-grained green limestone overlain by beds of pure, earthy, crinoidal, green limestone. Atrypa . . . . .2.10 m

Environments

The F2j reefs are entirely isolated within F2i Reticularia pachyrhyncha shales which also form their substratum and locally their covering (plate II; plate VI, fig. 2). The shales on the flanks are not indented in the reef as are the limestones on the flanks of the F2h "reefs," but are built up against them at varying angles. This characteristic alone would indicate that they could not have formed in an environment strongly agitated by waves, but must have developed in calm waters. The reefs themselves exercise no influence on the surrounding area. Not only is there nothing to be observed on their flanks which could be interpreted as a talus of debris, but also there is no dispersion of limy sand or lime mud around them, as would have been expected in modern reefs, around which for several kilometers the sea is milky due to fine lime mud removed from them during the aftermath of a storm.

The immediate environment of these "reefs" differs from the interreefal environment. Many of these differences are difficult to determine because of the diapiric displacements which these limestone lenses have undergone in the shales. Where contacts are normal, shales are crowded with fossils in a narrow halo around the reef. The crinoids indicate particularly well that these fauna came not from the "reef," but developed in place. The crinoids form thin limestone beds interstratified with the shale; some distance from the reef, the limestone beds are lenticular and finally absent. In certain cases, they invade the upper part of the limestone lens where the usual constructing organisms are absent (Grands Fonds quarry, plate III, fig. 1).

In an earlier work [20], I recorded that Alveolites colonies found in the shales at the contact with the reef had the margins of their polyps stained with iron salts, indicating their development in place. The fauna has a stratigraphic distribution which does not correspond with biologic zonation of the "reef" either quantitatively or qualitatively. The massive polyps (Alveolites, Acervularia, and Hexagonaria) and the branching variety (Alveolites and Thamnopora) are generally abundant near the contact, but brachiopods and crinoids are the dominant fossils and persist longer. The vertical distribution of this fauna would have to be studied by establishing its age relative to the zones of the "reef," but the phenomena of interreefal buildup (plates I and II) and of tectonic deformation considerably complicate the problem. Some distance from the "reef," the flanking shales are nodular and poor in fossils.

Final burial

F2i shales are progressively finer upwards and their fauna is impoverished until they pass into the extremely fine-grained shales of the Matagne (F3) beds (plate 2) which have an extremely depauperate fauna. This indicates that subsidence caused an end of the development of the F2j "reefs" because of the inability of the constructing corals to tolerate mud. The corals locally resisted mud infiltration up to the time of Matagne deposition but generally they were engulfed in the upper part of the Reticularia pachyrhyncha shales (F2i).

Conclusions

The constructed limestone lenses of the F2j stage are characterized by:

1. a simple morphology free from structural characters which could indicate actions of currents or waves; senile characteristics comparable to those of present-day coral reefs which include lateral spreading, abrasion of reef surfaces, death of coralline colonies at the crest of the structures, and the formation of beach rocks on margins.

2. an essentially coralline fauna (tabulates and rugose) having a small size (which must be due to the environment because larger ones exist under other environmental conditions), poor in species, tolerant to mud, associated with a

problematic organism called Stromatactis which is also apparently a powerful constructor. Stromatoporoids are rarely found. They are generally lamellar, which shows that the environment was not favorable for them.

3. the preservation, in growth position, of by far the larger number of constructing organisms, locally, particularly in the lower phase, in a very steep attitude conformable to reefal zonation. The forms which have been removed from their growth position are generally small and appear chiefly around the flanks and in the medial position of the lens which corresponds to shallowest environment.

4. the absence of horizontal biologic zonation or of marked adaptation.

5. the absence of sorting or of a particular concentration of bioclastic material in a privileged location.

6. the absence of any influence by the constructed limestone on the surrounding area and the affect on the development of the lens.

THE "REEFS" OF THE MIDDLE HORIZON F2h

The study of the F2h "reefs" is not as well advanced as that of the F2j "reefs" because they are less often and less well exploited. Their more massive structure lacks any readily discernible zones. They have a uniformly gray to white color in which organisms are not readily recognized.

Morphology

These structures are massive and much larger than the coralline lenses of the F2j stage. They are commonly 1 kilometer long and some 150 m high. They are not hemispherical, but are interfingered in the F2g stratified limestone which comprises their substratum and a proportion of their lateral equivalent (plates II and IV, fig. 3).

Vertical Development and Constructing Organism

The principal constituents seem to be massive and branching stromatoporoids, brachiopods (particularly Gypidula), and colonial corals (tabulates and tetracorals) in variable proportions with which are associated some Receptaculites, crinoids, solitary rugose corals, distributed erratically throughout the structure.

Because no quarry has penetrated very deeply into these "reefs," the vertical distribution of the constructing organisms is known only in the upper part - and that still imperfectly. The northern quarry at Frasnes-les-Couvin has provided the most important observations. This quarry has cut into the reef for about 70 m. The section (plate III, fig. 3) allows the determination of succession from crest to the deepest portion which has been exploited:

1. Massive limestone with Stromatactis-like growths and with tabulate corals and branching Stromatopora which are rare at the base and more abundant at the top . . . . 4 m
2. Massive and lamellar stromatoporoids, more abundant upwards, arranged in an irregular manner and branching Alveolites . . 12 m
3. Sporadic growths of Stromatactis type with tabulate corals, branching stromatoporoids, and scattered brachiopods . . . . 8 m
4. Numerous branching tabulate corals and brachiopods arranged in zone with scattered gastropods . . . . 5 m
5. Limestone more and more crinoidal at the top, embracing massive and lamellar stromatoporoids. A large, overturned colony of Hexagonaria 60 cm in diameter was observed . . 8 m
6. Stromatactis-like growth, branching Alveolites, and rare ball-shaped stromatoporoids . . . . 2 m
7. Lamellar and ball-shaped stromatoporoids of moderate size, lamellar Alveolites, and solitary rugose corals . . . . 4 m
8. Numerous brachiopods, lamellar and ball-shaped stromatoporoids of small and moderate size with Thamnopora, solitary rugose corals, and gastropods . . . . 3 m
9. Lamellar stromatoporoids and numerous crinoids associated with a few brachiopods . 3 m
10. Very large stromatoporoid balls and thick platy stromatoporoids associated with crinoids which are very irregularly distributed from one stratum to another . . . . .20 m

The Lion "reef" at Frasnes-les-Couvin has a rather different composition in the 70 m exposed in its upper portion. It is much richer in brachiopods and Hexagonaria but poorer in massive stromatoporoids. Receptaculites, not observed in the northern "reef," are also recorded. From top to bottom, the following strata are recognized:

1. Massive stromatoporoid limestone containing both lamellar and branching forms; Thamnopora; and, at the top, large colonies of Hexagonaria and Receptaculites . . . . . .17 m
2. Lamellar stromatoporoids; Hexagonaria, which may be abundant at certain horizons; massive and branching Alveolites; abundant brachiopods (particularly Gypidula and Atrypa); and Orthoceras at the base . . . . .15 m
3. Predominantly brachiopods in a limestone with a calcite growth resembling Stromatactis; branching tabulate corals including Thamnopora, Alveolites, and Plagiopora; Hexagonaria, Receptaculites, and solitary rugose corals of the Disphyllum type . . . . 15 m

The two outcrops, however, are not comparable. The northern quarry is open in the axial portion of the "reef" and the Lion quarry is situated in a submarginal position, thus corresponding to a lower part of the mass, probably rather near the base. An examination of the basal extremity of the "reef" in l'Ermitage cutting at

Boussu-en-Fagne (plate III, fig. 4b) seems to confirm this and shows, over a thickness of about 16 m, a large preponderance of brachiopods (Gypidula, Atrypa, and Schizophoria) with sporadic branching tabulate corals such as Plagiopora, Alveolites, finely laminated stromatoporoids, solitary rugose corals, trilobites, and crinoids which form a variable porportion of the limestone matrix.

Correlation of the three partial sections (Lion quarry, northern quarry, and the western basal extremity of the Boussu-en-Fagne "reef") permits reconstruction, with a fair degree of probability, the complete vertical section of an F2h "reef," from top to bottom:

1. Massive stromatoporoids predominate with some branching lamellar forms, branching tabulate corals, streaks with brachiopods and crinoids. This zone comprises more than half the "reef."
2. Transition zone (about 20 m at Lion quarry, Frasnes-les-Couvin) with lamellar stromatoporoids, Hexagonaria, and brachiopods. Some branching tabulate corals.
3. Stromatactis zone with predominant brachiopods and branching tabulate corals, Hexagonaria, solitary rugose corals, Disphyllum, and Receptaculites.
4. Brachiopod zone in which brachiopods are most common; some branching tabulate corals and solitary rugose corals.

This reconstructed section compares rather well with that of the F2g limestones forming the Philippeville massif which substitute for the F2h lenses on the southern border of the Dinant basin. The F2g lenses, and indications that they substitute for the F2h lenses, were examined in a railway cut southwest of the Neuville Nord station (plate IV, fig. 1).

The F2h "reefs" are limestone masses containing brachiopods and polyps in their lower part and stromatoporoids, first lamellar, then massive, in their upper part. The environment in the earlier phase of their history was not favorable for the constructing activity of stromatoporoids; later, the massive forms, as water depth diminished, built up the large masses. It is noticeable that in the stromatoporoid phase the constructing organisms are arranged chaotically; a fair number are overturned, even those as large as Hexagonaria recorded in the northern quarry (plate III, fig. 3). The matrix of the rock, locally crinoidal, contains fragments of stromatoporoids and sheets of bioclastic rounded sand grains. These indicate that this phase existed in a marine zone of considerable turbulence and that the lower phase existed at greater depth, like the F2j "reef." Towards the zone of transition between the two phases, Hexagonaria and Alveolites colonies may be more than 1 m at the base and 50 to 60 cm high, which is not the case in the F2j "reefs." It is also significant that Stromatactis and the stomatoporoids are mutually exclusive. Stromatactis appears in the lower phase and later at the crest where, after subsidence, the massive stromatoporoids could not exist (plate III, fig. 3). More marked subsidence is indicated by F2i shales; polyps may be very large (Hexagonaria colony at Lion quarry is 0.70 m long and 0.30 m high).

The Substratum

The reef rests on approximately 10 m of argillaceous stratified limestone which is earthy and locally subnodular. The limestone contains streaks of pure, even crystalline, more or less strongly crinoidal material in which nonfossiliferous beds alternate with those containing brachiopods (Atrypa, Gypidula, Athyris, Spirifer) (plate VI, fig. 4). In the upper part, Alveolites, Hexagonaria, and even lamellar stromatoporoids appear, announcing the F2h reefal facies. The limestone is generally poorly exposed in the area of the "reefs." At Boussu-en-Fagne, where the F2d and F2h reefs are superposed (plate VI, fig. 5), the basal F2d limestone seems to be absent on the axis of superposition. Maillieux [31] states that the two reefs were in fault contact. It is also possible that the F2h reef, at this horizon, follows the F2d reef without interruption. Work has been started on this problem but no results are as yet available.

The Environment

The lower part of the reef is covered by the stratified F2g limestone which also forms the substratum. In the interreefal area (plate VI, fig. 6), this horizon, which is about 18 m thick, is represented in the lower half by subnodular to nodular limestones which are argillaceous, earthy, containing few small brachiopods and solitary rugose corals. The upper part is composed of limy shales overlain by alternating shales; limy shales; and fine-grained, locally pyritic, argillaceous limestones. This sequence is exhibited in a trench dug about 500 m west of the Boussu-en-Fagne reef (plate III, fig. 4a).

This sequence is 30 to 35 m thick at the reef margins; its fauna is richer; and its limestone is purer and more obviously crinoidal. Fossils are massive and lamellar stromatoporoids, massive and branching Alveolites, Thamnopora, brachiopods, and coarse crinoids (plate III, fig. 4b, the section taken on l'Ermitage road at the western end of the Boussu-en-Fagne reef). Microscopic examination of thin sections shows that the material is somewhat sorted radially from the reef, but grain size varies from the base to the crest as it does within the massive limestone. In the lower beds, grain size is generally fine (0.10 to 0.20 mm); the matrix is a fine bioclastic sand composed of echinoid-spine fragments, crinoids, gastropods, bryozoans, foraminifers, shells, and algae (Girvanella) enveloping angular fragments of larger organisms. The over-

lying beds are coarser grained (0. 40 to 0. 80 mm); the bioclastic matrix includes fragments of the builders Alveolites, stromatoporoids, branching tabulate corals, bryozoans, whole ostracods, and solitary rugose corals.

Undoubtedly, the F2h limestone lenses, unlike the F2j reefs, were exposed to the action of turbulent waters and, therefore, clearly influenced the surrounding sedimentation. Also, unlike the F2j lenses, the F2h masses are not distinctly separate from their laterally blanketing sediments, especially with the F2g limestones with which they are interfingered (plate VI, figs. 3 and 4). Microscopic study of the lithologic constituents of the limestone intercalations at Lion reef, Frasnes-les-Couvin, shows a composition identical with that of the marginal limestones with a bioclastic matrix composed of elements of reefal origin.

The stratified F2g limestones are only a small portion of the lateral blanketing sediments; they are essentially products of the disintegration of a limestone mass built over contemporaneous silting. The blanketing [Tr. : of the reef] is complete in the F2i shales. At the contact with the "reef," the shales show some influence of the reefal environment not by the accumulation of fine debris in the form of talus but by the presence of a rich autochtonous fauna which is reefal in character (Hexagonaria, massive and and branching tabulate corals, solitary rugose corals, Receptaculites, brachiopods, and crinoids) with the exclusion of stromatoporoids. A few large Hexagonaria colonies (one in Lion quarry is over 16 cm in diameter and 40 cm high), completely overturned, show the violence of the turbulence in spite of the subsidence which caused the termination of reefal development. This transitional period was of short duration; above the few meters of shales crowded with reefal organisms are fossil-impoverished shales interstratified with small beds of subnodular limestone or beds of fine-grained limestone nodules. The only fauna present are scattered brachiopods, crinoids, and a few solitary rugose corals. At certain horizons, such as the base of the Lion reef at Frasnes-les-Couvin (plate III, fig. 5), rare Hexagonaria indicate the continuance of coralline development not far away, perhaps even the upper part of the nearby F2h mass which resisted burial.

Final Burial

The crests and upper flanks of the F2h "reefs" are not so exposed that the nature of the surface buried by the F2i shales can be defined. They have been truncated by erosion. The inclined reefs are exposed as promontories which now stand above the shaly plain which originally engulfed them. It would be of the greatest interest to ascertain whether the shales rest on an erosional surface corresponding to the low-tide level reached by the "reefs" in their senility. Where the contact is preserved and exposed, as at the cemetery quarry at Boussu-en-Fagne, it is too local to allow comment. Although the morphologic characters do not show lateral expansion, as might be expected under the circumstances, the faunal succession of the shales immediately overlying the reef is similar to that of the flanks of the basal portion of the "reef." This sequence is essentially the same as that of the F2i shales in the cemetery quarry of Boussu-en-Fagne which was described earlier (compare the lower part of the section at the access cut of Lion quarry, plate III, fig. 6).

From the contact outward, the stromatoporoids are absent from the shales, but coralline fauna, still tolerant to mud, are more numerous than in the F2j reefs. A reefal mass was not constructed, for subsidence drowned it rather rapidly, as the sequence described above has shown. It is assumed that the crest of the F2h lenses did not exist near the water level, at least in cases where observations have been made, but redescended during the course of a gentle subsiding movement to a depth at which stromatoporoids could not exist but at which coralline fauna could.

Conclusions

The F2h constructed limestone lenses are not entirely composed of stromatoporoids, as would generally be assumed. Ecologically, they represent the superposition of two environments. They probably originated beneath or toward the lower limit of the zone of marine turbulence with a fauna essentially composed of corals, brachiopods, and Stromatactis. They were raised into the zone of turbulence where stromatoporoid reefs were developed. Reefal development continued until subsidence, marked by invading shales, caused termination of construction. It is clear that environments required by Devonian corals were completely different from the requirements of contemporary stromatoporoids. The Devonian forms were remarkably more tolerant to mud and could live at greater depths. The stromatoporoids could adapt themselves to muddy water and only prospered in the zone of agitation; in the Devonian seas, they played the role of present-day madreporian corals.

"REEFS" OF THE LOWER LEVEL F2d

Limestone masses constructed in the lower F2d level are few in number and have not yet been exploited. Because of this, they are not well observed and known. They seem to have been constructed under more variable conditions than those of the upper horizons. The Arche "reef" at Frasnes-les-Couvin (plate III, fig. 5), the only one at all exploited, appears to be rather different, at least in its lower part, from the reefs at Boussu-en-Fagne.

The reef rests on F2c shales which, in their

upper part, are crowded with Disphyllum associated with Alveolites, Thamnopora, and Atrypa reticularis. The lower part, about 30 m high, consists of a pink to reddish limestone which was exploited as a marble similar to that forming the lower phase of the F2j reefs and having an essentially coralline fauna. From the base upward, the F2d consists of:

1. Zoned limestone. Zoning is due to the predominance of lamellar colonies of Alveolites associated with lamellar stromatoporoids, algae, branching tabulate corals (Thamnopora), disphyllids, brachiopods, and crinoids . . . . . 4 m
2. Irregular colonies of Alveolites with lamellar stromatoporoids and brachiopods, giving the limestone a disordered appearance . .3.5 m
3. Zoned limestone. Zoning is due to numerous finely lamellar Alveolites associated with abundant lamellar stromatoporoids, irregular and large Alveolites, brachiopods concentrated in pockets, scattered Receptaculites, disphyllids, and Thamnopora . . . . .17.5 m
4. Limestone, grading from red to gray, transition to the upper phase of the "reef." Fauna includes Alveolites, lamellar stromatoporoids, and brachiopods (Gypidula), which are increasingly dominant . . . . 7.0 m
5. Gray limestone containing brachiopods (Gypidula, Atrypa) associated with Alveolites and lamellar stromatoporoids, disphyllids, and crinoids . . . . .8.0 m
6. Massive stromatoporoids associated with brachiopods in local concentrations . . 20.0 m

The Arche reef resembles F2h reefs with a lower coralline phase and an upper massive stromatoporoid phase. The lower phase is more obvious in the F2j reefs because of its red color, but stromatoporoids clearly play a larger part in it. It is as if this reef started to build itself at a greater depth than that at which the F2h reefs started, but a little more shallow than that of the F2j reefs. The Arche reef did not remain as long as did the F2h reefs in the zone of agitation. Unfortunately, I have been unable to determine the cause of the reef's rapid extinction, but, according to the lithologic character of the F2c shales which finally buried it, the cause must have been sudden subsidence.

Because the Boussu-en-Fagne "reef" has been exploited only slightly in a few small excavations on its western flank, it has not been possible to explore it as well as the other "reefs" have been explored. It is a much larger mass than the Arche "reef." Perhaps, it is joined at its crest with the overlying F2h "reef." It appears to be very different from the Arche "reef." From base to top, it is composed of light-gray to whitish limestone with some very localized reddish spots. It is rich from the base upwards in lamellar or, less commonly, ball-shaped stromatoporoids; lamellar Alveolites; brachiopods (Gypidula and Atrypa); solitary rugose or disphyllid corals; Thamnopora; and ostracods.

THE FRASNIAN SEDIMENTARY RHYTHM

A study of the Frasnian sedimentary complex confirms the ecologic conclusions drawn from the study of horizons F2d, F2h, and F2j. The general diagrammatic cross section of the Frasnain (plate II) and the detailed section of the middle Frasnian sketched in l'Ermitage roadcut at Boussu-en-Fagne (plate IV, fig. 2) permit the following conclusions:

1. The base (zone F1a of Spirifer tenticulum) of the Fromelennes bed (lower Frasnian - F1) marks a short-lived subsidence which terminated the stromatoporoid limestone of the upper Givetian. It consists of limestones which are increasingly subnodular up the section and which grade into limy shales and shales interstratified with subnodular limestones locally replaced by shales.
2. The middle zone, F1b, marks a progressively more favorable environment. At the bottom of this zone, the limestones are very argillaceous and unfossiliferous, or slightly rich in ostracods, gastropods, and polyps. These are overlain by lamellar stromatoporoids, then massive stromatoporoids, massive and branching tabulate corals, and solitary rugose forms. The fossiliferous lenses alternate with less extensive unfossiliferous beds of very fine and frangible limestone. Near the top of the zone, on beds literally stuffed with ball-shaped stromatoporoids, erosional surfaces resemble beach rocks of reefal shores and corrosional phenomena on the surface of stromatoporoid colonies; these beds are very similar to beds containing disarticulate brachiopods (belonging to the overlying zone) which undoubtedly establish the very shallow depth of the environment in which the stromatoporoids flourished.
3. Renewed subsidence eliminated the stromatoporoids and allowed the development of brachiopods and pelecypods (Myophoria, Lyriopecten, and others) in argillaceous limestones and calcareous shales interstratified with shaly lenses in which beds containing Disphyllum are intercalated.
4. The Frasnes (middle Frasnian - F2) marks the accentuation of the subsidence which determines the disappearance of coralline fauna.
5. Horizon F2a, with Spirifer orbelianus, (called the "monster zone" by J. Gosselet) is represented by nodular shales passing at the crest into a few limestone beds.
6. Renewal of subsidence caused deposition of fine-grained shales which are progressively nodular upward. These shales mark the start of the Receptaculites zone (F2b), but, for 25 m, contain only an impoverished and depauperate fauna. Near the top, in more limy and less nodular shales, the environment was more favorable, as is shown by the presence of Schellwienella, Douvillina, Productella, Chonetes, Atrypa, Pugnax, pelecypods, solitary rugose corals, and Receptaculites. The greater frequency of nod-

ules at the top and the appearance of limestone also indicate a more favorable environment and introduce the F2c environment which acted as the substratum for the F2d reefs.

It is possible that this very clear amelioration of the environment is not due exclusively to the thickness of sediments deposited but to epeirogenic uplift. It is even probable, if the mere 50 m between the very fine-grained unfossiliferous depauperate shales at the base of the Receptaculites zone and the substratum of the F2d reef at Boussu-en-Fagne are considered. This movement was probably a warping uplift and, for that reason, could have affected neighboring regions differentially. This would explain the differences outlined earlier between the F2d "reef" at Arche with its coralline fauna in the lower part and prepared by a substratum approximately 5 m thick of Disphyllum shales and the "reef" of the same age at Boussu-en-Fagne where an analogous thickness of nodular limestones with Receptaculites, rugose corals, and brachiopods acts as the base for a mass apparently directly built up by stromatoporoids in association with brachiopods and tabulate corals.

7. The lateral covering of the F2d constructed lenses is composed of F2c limestones in which they are intercalated and which contain essentially the reef fauna and bioclastic sands. At some distance from the reef, the F2c horizon is replaced by limestones and nodular shales. The subsidence which followed a period of relative stability during which the F2c limestones were deposited is marked by the deposition of the F2e Leiorhynchus formosus shales which, after a brief nodular interval with a coralline fauna still accompanied by brachiopods, are very fine grained and, for a thickness of 40 m, contain a diminutive fauna in which goniatites, gastropods, and solitary rugose corals predominate. These are overlain by 50 m of nodular shales. Above the nodular shales are limestones with branching tabulate corals.

8. A minor oscillation at the F2f Xenocidaris mariaburgensis zone resulted in the deposition of limy shales with nodules in which remains of echinoids, trilobites, brachiopods, and pelecypods can be found.

9. The F2g stratified limestone is generally argillaceous and slightly crinoidal. It contains brachiopods and branching tabulate corals and, at the top, Hexagonaria and lamellar stromatoporoids (plate III, fig. 4b, lower part immediately under F2h). It is on this substratum that the F2h reefs are built up.

10. The F2h reefs begin with a coral and lamellar stromatoporoid fauna. Lateral burial by F2g limestones correspond to one phase of reef development; the greater part is formed by the F2i shales containing Reticularia pachyrhyncus deposited during subsidence. The stromatoporoids struggled for some time against the effects of subsidence but eventually were overcome. Their associated corals, less sensitive to the deepening of the sea bottom and to the influx of mud, managed to maintain themselves longer.

11. After a short period of continued subsidence, even the F2i shales became impoverished, almost to the total absence of their fauna. Environmental conditions, however, improved and corals, both tabulate and rugose, appeared.

12. The F2j lenses were constructed on a relatively stable sea bottom. After the formation of the middle of this reef, which managed to reach the zone of agitation but not high enough to allow for the development of stromatoporoids, subsidence resumed and coralline growth ended.

13. The Matagne shales (upper Frasnian - F3) mark maximum subsidence in the upper Devonian.

It is hardly necessary to emphasize that this rhythmic succession clearly shows that the coralline and stromatoporoid development correspond to well-determined bathymetric conditions. A subsidence of some importance always leads to the demise of stromatoporoids, while tabulate and rugose corals are able to survive for some time. Improved conditions by uplift of the sea bottom first allowed renewed coralline, then stromatoporoid, development. Sudden uplift as the result of epeirogenic activity can lead directly to stromatoporoids without passing through a coralline stage. Therefore, it is very clear that the stromatoporoids could only flourish at shallow depths while Devonian corals, both tabulate and rugose, could exist and construct at greater depths.

GENERAL CONCLUSIONS

Constructed limestones of the Frasnian in the Ardennes are the result of two types of constructing organisms: stromatoporoids adapted exclusively to shallow water and tabulate and colonial corals, more tolerant of deeper and muddier water. Bathymetric conditions determined their constructive activity. As a result, three types of "reefs" were built:

1. Reefs formed of massive stromatoporoids built up in the zone of agitation (perhaps the F2d type at Boussu-en-Fagne).
2. Coral reefs constructed beneath the zone of agitation (F2j "reefs").
3. Mixed reefs begun by corals and ended by stromatoporoids (F2d "reef" at Arche) or begun in an intermediate zone between the depth suitable for the construction of the F2j type and the agitated zone (F2h "reefs" at Boussu-en-Fagne and Lion quarry, Frasnes-les-Couvin). To each of these conditions there corresponds, of course, a particular morphologic structural type.

One may ask whether the Frasnian corals were not capable of erecting their massive lenses in agitated waters as did stromatoporoids with which they coexisted in the F2h reefs and whether the lenses they built during the Frasnian were at greater depths is not simply the result of circumstances external to their particular capabilities. It is quite certain that they could live

in the zone of agitation because they accompany the stromatoporoids in the F2h reefs and are even more robust. They continued to thrive when subsidence caused the demise of the stromatoporoids. It therefore seems that they theoretically were capable of constructing "reefs" in the zone of agitation but in this environment found themselves in competition with stromatoporoids. The stromatoporoids found it impossible to exist below the zone of agitation, but this environment was not the most favorable for the corals either, as they were not as large as they were in the agitated waters.

Contrary to what Lowenstam imagined in his recent publications [27, 28], any type of constructed limestone, according to geologic circumstances, cannot develop in the zone of agitation regardless of the nature of the constructing organisms. A type of organogenic construction cannot be defined and characterized without paying heed to the biologic role and the requirements of the constructing organisms in the framework of geologic phenomena.

It seems permissible to suppose that if the F2j "reefs" in the Philippeville area are better developed than those on the southern border of the Dinant basin, it is because the Frasnian subsidence was felt less strongly in the northern region.

REFERENCES

1. Bellière, J., NOTE SUR LE CALCAIRE FAMENNIEN DE BAELEN ET SES STROMATACTIS [OBSERVATIONS ON THE FAMMENIAN LIMESTONE OF BAELEN AND ITS STROMATACTIS]: Soc. Géol. Belgique, Bull., v. 76, p. B 115-128, 1953.

2. Cumings, E. R., and R. R. Shrock, THE SILURIAN CORAL REEFS OF NORTHERN INDIANA AND THEIR ASSOCIATED STRATA: Indiana Acad. Sci., Proc. for 1926, p. 71-85, 1927.

3. ______________, NIAGARAN CORAL REEFS OF INDIANA AND ADJACENT STRATA AND THEIR STRATIGRAPHIC RELATIONS: Geol. Soc. Amer., Bull., v. 39, p. 579-620, 1928.

4. Cumings, E. R., REEFS OR BIOHERMS ?: Geol. Soc. Amer., Bull., v. 43, p. 331-352, 1932.

5. Delhaye, F., ÉTUDE DE LA FORMATION DES RÉCIFS DE CALCAIRE ROUGE À RHYNCHONELLA CUBOIDES (NOTE PRÉLIMINAIRE) [A STUDY OF THE FORMATION OF RED LIMESTONE REEFS CONTAINING RHYNCHONELLA CUBOIDES, (PRELIMINARY NOTE): Soc. Géol. Belgique, Ann., v. 35, p. b 243-253, 1907-1908.

6. Delhaye, F., LA STRATIFICATION ET LA SCHISTOSITÉ DES SCHISTES ARGILEUX AU VOISINAGE DES RÉCIFS DE CALCAIRE ROUGE À ACERVULARIA ET RHYNCHONELLA CUBOIDES [STRATIFICATION AND SCHISTOSITY OF ARGILLACEOUS SHALES IN THE VICINITY OF RED LIMESTONE REEFS CONTAINING ACERVULARIA AND RHYNCHONELLA CUBOIDES]: Soc. Géol. Belgique, Ann., v. 35, p. B 342-346, 1907-1908.

7. ______________, ÉTUDE DE LA FORMATION DES RÉCIFS DE CALCAIRE ROUGE À ACERVULARIA ET HYPOTHYRIS CUBOIDES (2^e NOTE) [A STUDY OF THE FORMATION OF RED-LIMESTONE REEFS CONTAINING ACERVULARIA AND HYPOTHYRIS CUBOIDES (SECOND NOTE)]: Soc. Géol. Belgique, Ann., v. 40, p. B 469-481, 1912-1913.

8. ______________, SUR LES RELATIONS DES SCHISTES DE MATAGNE AVEC LES RÉCIFS DE CALCAIRE ROUGE DU BORD SUD DU BASSIN DE DINANT [ON THE RELATIONSHIP BETWEEN SHALES OF THE MATAGNE AREA AND RED-LIMESTONE REEFS OF THE SOUTHERN BORDER OF THE DINANT BASIN]: Soc. Géol. Belgique, Ann., v. 40, p. B 481-491, 1912-1913.

9. ______________, DES DIFFÉRENCES DE FACIES DES RÉCIFS À ACERVULARIA DE LA BANDE FROMELENNES-TRÉLON ET DU MASSIF DE PHILIPPEVILLE [DIFFERENCES BETWEEN FACIES OF REEFS CONTAINING ACERVULARIA OF THE FROMELENNES-TRÉLON BAND AND THOSE OF THE PHILIPPEVILLE MASSIF]: Soc. Géol. Belgique, Bull., v. 42, p. 86-94, 1932.

10. Dumon, P., ÉTUDE DU FRASNIEN EN BELGIQUE [A STUDY OF THE FRASNIAN IN BELGIUM]: Assoc. Ing. Écoles des Mines de Mons, Publ., v. 2, no. 29, p. 119-230, 1927-1928.

11. ______________, COMPTE RENDU DE L'EXCURSION DU 11 JUIN 1932 AUX CARRIÈRES DE MARBRE ROUGE DE VODELÉE ET DE SOULME [A REPORT ON THE EXPEDITION OF JUNE 11, 1932, TO THE RED-MARBLE QUARRIES OF VODELÉE AND SOULME]: Soc. Géol. Belgique, Bull., v. 42, p. 118-128, 1932.

12. Dupont, E., SUR L'ORIGINE DES CALCAIRES DÉVONIENS DE LA BELGIQUE [ON THE ORIGIN OF DEVONIAN LIMESTONE IN BELGIUM]: Acad. Roy. Belgique, Bull., ser. 3, v. 2, p. 264-280, 1881.

13. ______________, LES ÎLES CORAL-

LIENNES DE ROLY ET DE PHILIPPE-VILLE [THE CORALLINE ISLANDS OF ROLY AND PHILIPPEVILLE]: Mus. Roy. Hist. Nat. Belgique, Bull., v. 1, p. 86-160, 1882.

14. Dupont, E., SUR LES CALCAIRES FRASNIENS D'ORIGINE CORALLIENNES ET SUR LEUR DISTRIBUTION DANS LE MASSIF PALÉOZOÏQUE DE LA BELGIQUE [FRASNIAN LIMESTONES OF CORALLINE ORIGIN AND THEIR DISTRIBUTION IN THE PALEOZOIC MASSIF OF BELGIUM]: Acad. Roy. Belgique, Bull., ser. 3, v. 10, p. 21-38, 1885.

15. ____________, RÉSUMÉ DES EXCURSIONS DE MARIEMBOURG ET DE BOMAL DANS LES TERRAINS CORALLIGÈNES [SUMMARY OF THE MARIEMBOURG AND BOMAL EXPEDITIONS IN CORALLIGENOUS REGIONS]: Soc. Géol. Belgique, Bull., v. 5, P.V., p. 131-134, 1891.

16. ____________, LES CALCAIRES ET SCHISTES FRASNIENS DANS LA REGION DE FRASNES [FRASNIAN LIMESTONES AND SHALES IN THE FRASNES REGION]: Soc. Géol. Belgique, Bull., v. 6, Mém., p. 171-218, 1892.

17. Grabau, A. W., PALEOZOIC CORAL REEFS: Geol. Soc. Amer., Bull., v. 14, p. 337-352, 1903.

18. Hadding, A., THE PRE-QUATERNARY SEDIMENTARY ROCKS OF SWEDEN. VI. REEF LIMESTONES: Lunds. Univ. Arsskr., N. F., v. 37, no. 10, 1941, 137 p.

19. Harroy, J., LES MASSES DE CALCAIRE CONSTRUIT ET LEURS RELATIONS AVEC LES SCHISTES QUI LES ENVIRONNENT. CONTRIBUTION À L'ÉTUDE DU FRASNIEN [CONSTRUCTED-LIMESTONE MASSES AND THEIR RELATIONSHIP TO THE SURROUNDING SHALES. CONTRIBUTION TO THE STUDY OF THE FRASNIAN]: Soc. Géol. Belgique, Bull. v. 37, p. M 315-333, 1910.

20. Lecompte, M., LE GENRE ALVEOLITES LAMARCK DANS LE DÉVONIEN MOYEN ET SUPÉRIOR DE L'ARDENNE [THE GENUS ALVEOLITES LAMARCK IN THE MIDDLE AND UPPER DEVONIAN OF THE ARDENNE]: Mém. Mus. Roy. Hist. Nat. Belgique, v. 60, 1933, 50 p.

21. ____________, CONTRIBUTION À LA CONNAISSANCE DES "RÉCIFS" DU FRASNIEN DE L'ARDENNE: ÉTUDE LITHOLOGIQUE DU "RÉCIF" EXPLOITÉ A LA NOUVELLE CARRIÈRE DU CHÂTEAU GAILLARD A TRÉLON (FRANCE) [A CONTRIBUTION TO THE KNOWLEDGE OF FRASNIAN "REEFS" OF THE ARDENNE: A LITHOLOGICAL STUDY OF THE EXPLOITED "REEF" IN THE NEW QUARRY OF CHÂTEAU GAILLARD IN TRÉLON (FRANCE)]: Inst. Géol. Univ. Louvain, Mém., v. 10, p. 24-112, 1936.

22. Lecompte, M., CONTRIBUTION À LA CONNAISSANCE DES "RÉCIFS" DU DÉVONIEN DE L'ARDENNE: SUR LA PRÉSENCE DE STRUCTURES CONSERVÉES DANS DES EFFLORESCENCES CRISTALLINE DU TYPE "STROMATACTIS" [A CONTRIBUTION TO THE KNOWLEDGE OF DEVONIAN "REEFS" OF THE ARDENNE: ON THE PRESENCE OF PRESERVED STRUCTURES OF THE TYPE STROMATACTIS IN CRYSTALLINE EFFLORESCENCES]: Mus. Roy. Hist. Nat. Belgique, Bull., v. 13, no. 15, 1937, 14 p.

23. ____________, QUELQUES TYPES DE "RÉCIFS" SILURIENS ET DÉVONIENS DE L'AMERIQUE DU NORD: ESSAI DE COMPARAISON AVEC LES RÉCIFS CORALLIENS ACTUELS [SEVERAL TYPES OF SILURIAN AND DEVONIAN "REEFS" OF NORTH AMERICA: AN ESSAY COMPARING THESE WITH REAL CORALLINE REEFS]: Mus. Roy. Hist. Nat. Belgique, Bull., v. 14, no. 39, 1938, 51 p.

24. Lowenstam, H. A., BIOSTRATIGRAPHIC STUDIES OF THE NIAGARAN INTER-REEF FORMATIONS IN NORTHEASTERN ILLINOIS: Illinois State Mus., Sci. Pap., v. 4, 1948, 146 p.

25. ____________, MARINE POOL, MADISON COUNTY, ILLINOIS, SILURIAN REEF PRODUCER: Illinois, State Geol. Surv., Rept. Inv., no. 131, p. 153-188, 1948.

26. ____________, NIAGARAN REEFS IN ILLINOIS AND THEIR RELATION TO OIL ACCUMULATION: Illinois, State Geol. Surv., Rept. Inv., no. 145, 1949, 36 p.

27. ____________, NIAGARAN REEFS OF THE GREAT LAKES AREA: Jour. Geol., v. 63, no. 4, p. 430-487, 1950.

28. ____________, SOME NEW OBSERVATIONS ON NIAGARAN REEFS IN ILLINOIS: Illinois, State Acad. Sci., Tr., v. 45, p. 100-107, 1952.

29. Maillieux, E., QUELQUES MOTS SUR LE RÉCIF DE MARBRE ROUGE DE L'ARCHE, À FRASNES [REMARKS ON THE RED-MARBLE REEF OF L'ARCHE IN FRASNES]: Soc. Géol. Belgique, v. 27, p. 114-125, 1913.

30. Maillieux, E., QUELQUES MOTS SUR LES RÉCIFS FRASNIENS DE LA PLAINE DES FAGNES ENTRE NISMES ET CHIMAY [REMARKS ON THE FRASNIAN REEFS OF THE PLATEAU DES HAUTES FAGNES BETWEEN NISMES AND CHIMAY]: Soc. Géol. Belgique, Bull., v. 27, p. 114-125, 1913.

31. __________, NOUVELLES OBSERVATIONS SUR LE FRASNIEN ET EN PARTICULIER SUR LES PALÉORÉCIFS DE LA PLAINE DES FAGNES [NEW OBSERVATIONS ON THE FRASNIAN AND PARTICULARLY ON THE FOSSIL REEFS OF THE PLATEAU DES HAUTES FAGNES]: Soc. Géol. Belgique, Bull., v. 27, Mém., p. 67-104,1913.

32. __________, LE RÉCIF À PHACELLOPHYLLUM DE L'ADUGEOIR ENTRE FRASNES ET PETIGNY [THE REEF CONTAINING PHACELLOPHYLLUM OF ADUGEOIR BETWEEN FRASNES AND PETIGNY]: Soc. Géol. Belgique, Bull., v. 28, P. V., p. 25-27, 1914.

33. __________, NOUVELLE CONTRIBUTION À L'ÉTUDE DES RÉCIFS CORALLIGÈNES DU FRASNIEN [A NEW CONTRIBUTION TO THE STUDY OF CORALLIGENEOUS REEFS OF THE FRASNIAN]: Soc. Géol. Belgique, Bull., v. 28, p. 82-93, 1914.

34. __________, PRÉSENCE DE RÉCIFS CORALLIGÈNES DANS LE DÉVONIEN MOYEN [THE PRESENCE OF CORALLIGENOUS REEFS IN THE MIDDLE DEVONIAN]: Soc. Géol. Belgique, Bull., v. 29, p. 93-94, 1919.

35. Maillieux, E., CONTRIBUTION À L'ÉTUDE DU "MASSIF" DE PHILIPPEVILLE [A CONTRIBUTION TO THE STUDY OF THE PHILIPPEVILLE MASSIF]: Soc. Géol. Belgique, Bull., v. 36, p. 86-112, 1926.

36. Maillieux, E., and F. Demanet, L'ÉCHELLE STRATIGRAPHIQUE DES TERRAINS PRIMAIRES DE LA BELGIQUE [THE STRATIGRAPHIC SCALE OF THE PRIMARY REGIONS OF BELGIUM]: Soc. Géol. Belgique, Bull., v. 38, p. 124-131, 1928.

37. Shrock, R. R., WISCONSIN SILURIAN BIOHERMS (ORGANIC REEFS): Geol. Soc. Amer., Bull., v. 50, no. 4, p. 529-562, 1939.

38. Twenhofel, W. H., CORAL AND OTHER REEFS IN GEOLOGIC COLUMN: Amer. Assoc. Petrol. Geol., Bull., v. 34, no. 2, p. 182-202, 1950.

39. Vaughn, T. W., PHYSICAL CONDITIONS UNDER WHICH PALEOZOIC CORAL REEFS WERE FORMED: Geol. Soc. Amer., Bull., v. 22, p. 238-252, 1911.

40. Waring, W. W., and D. B. Layer, DEVONIAN DOLOMITIZED REEF D^3 RESERVOIR, LEDUC FIELD, ALBERTA, CANADA: Amer. Assoc. Petrol. Geol., Bull., v. 39, no. 2, p. 295-312, 1950.

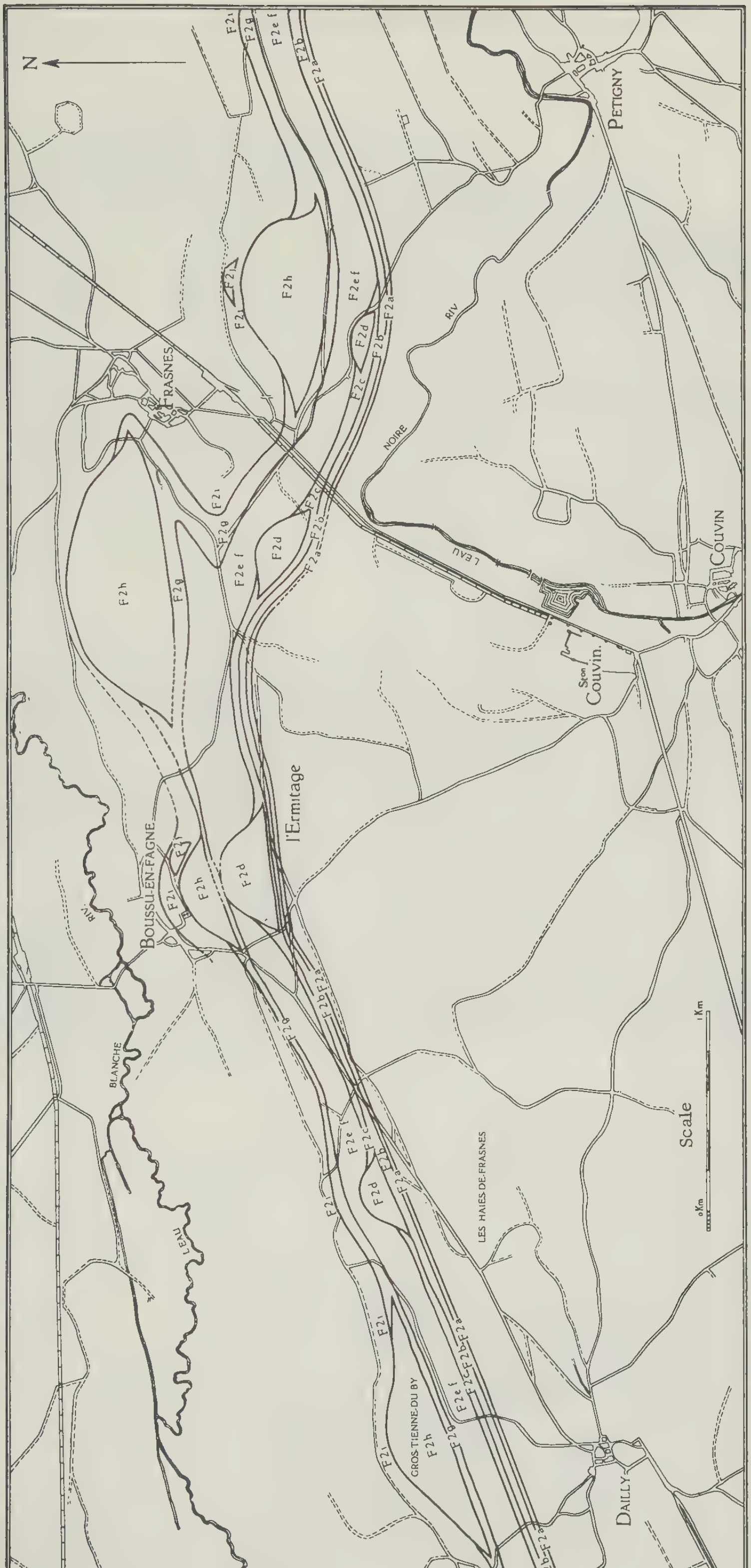
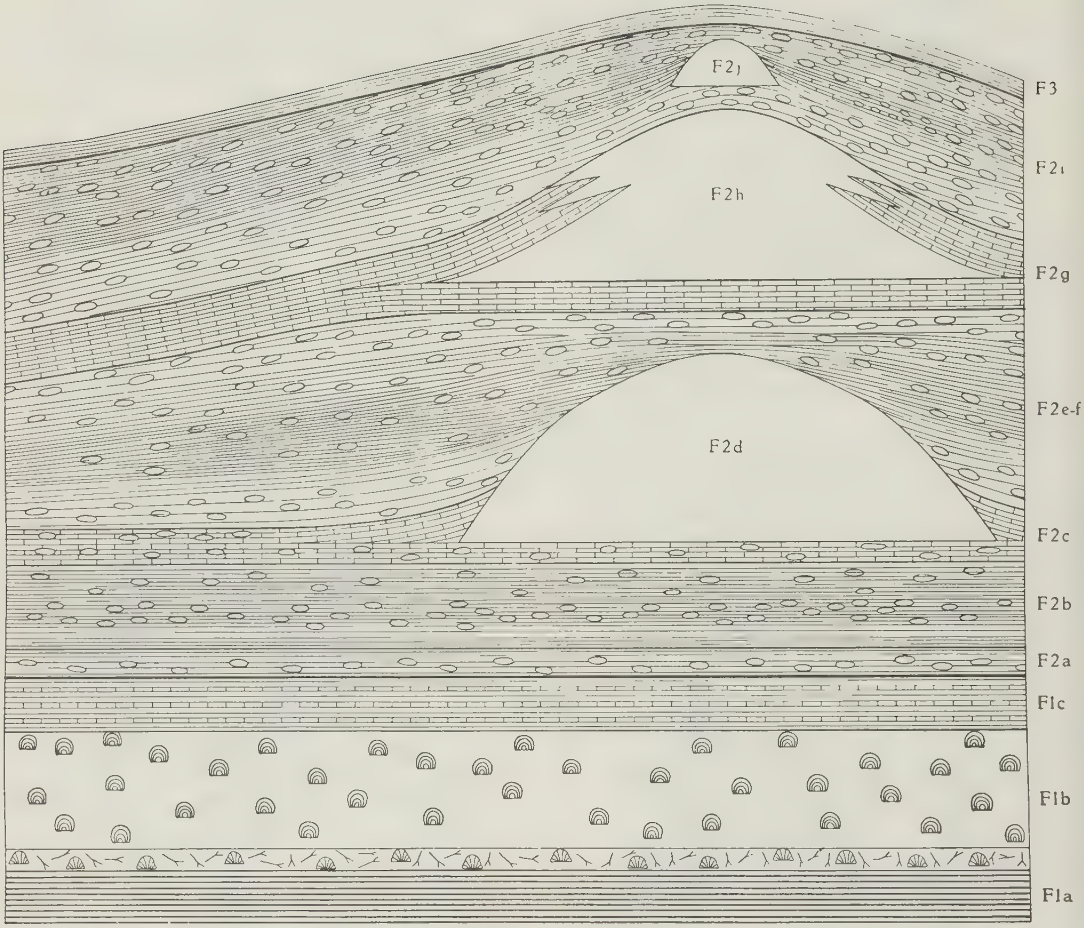


PLATE I. Map of the Frasnian reefs between Aublain and Frasnes-les-Couvin

PLATE II. General Frasnian section



EXPLANATION

F3. The Matagne containing Buchiola palmata

F2. The Frasnes containing Hypothyridina cuboides.

F2j: "Reefs" of the upper level
F2i: Shale containing Reticularia pachyrhyncha.
F2h: "Reefs" of the middle level
F2g: Stratified limestone
F2f: Gray shale containing Xenocidaris mariaburgensis
F2e: Green shale containing Leiorhynchus formosus.
F2d: "Reefs" of the lower level
F2c: Shale and stratified limestone
F2b: Green shale containing Receptaculites neptuni and Spirifer bisinus
F2a: Calcareous shale containing Spirifer orbelianus

F1. The Fromelennes containing Myophoria transrhenana and Lyriopecten gilsoni.

F1c: Calc-schist containing Myophoria transrhenana
F1b: Stratified gray limestone containing Stromatoporoides.
F1a: Area containing Spirifer tenticulum

Note: To facilitate drawing, the horizontal dimensions of the "reefs," particularly those of F2d and F2h, have been greatly shortened.

PLATE III. Columnar sections of Frasnian reefs

FIGURE 1. "Reef" F2j of the Grands Fonds quarry at Vodecée

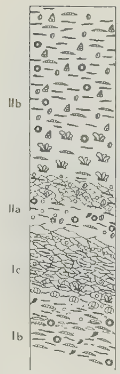


FIGURE 2. "Reef" F2j of the Croisettes quarry at Philippeville

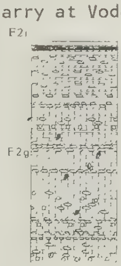


FIGURE 4a. 500 meters west of "reef" F2h

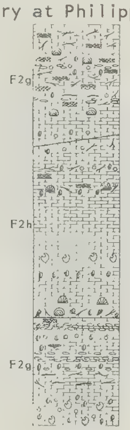


FIGURE 4b. Western border of "reef" F2h

FIGURE 4. Section of limestone F2g at Boussu-en-Fagne

FIGURE 3. "Reef" F2h of the North quarry at Frasnes-les-Couvin

FIGURE 5. "Reef" F2d of the L'Arche quarry at Frasnes-les-Couvin

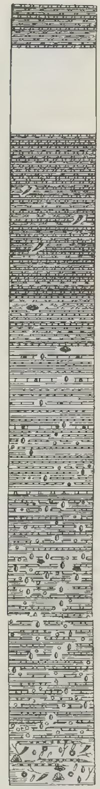


FIGURE 6. Section of shale F2i in the excavation in the Lion quarry at Frasnes-les-Couvin

Scale

0 20 m

LEGEND

Crinoids	Branched tabulate corals	"Acervularia"
Brachiopods	Hexagonaria	Gypidula
Gastropods	Stromatactis	Shale
Lamellar stromatoporoids	Rudimentary Stromatactis	Calc-schist
Massive stromatoporoids	Receptaculites	Massive limestone
Lamellar Alveolites	Heliophyllum helianthoides	Nodular or subnodular limestone
Massive Alveolites	Hypothyridina	Nodular limestone
Single Rugosa	Disphyllum	

PLATE IV. Sections of the middle Frasnian and stratified limestone from road cuts near Neuville Nord and Boussu-en-Fagne

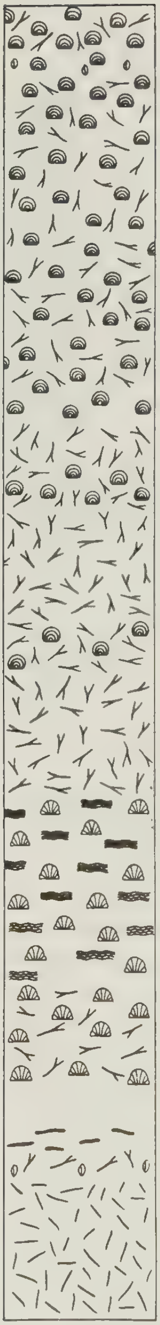
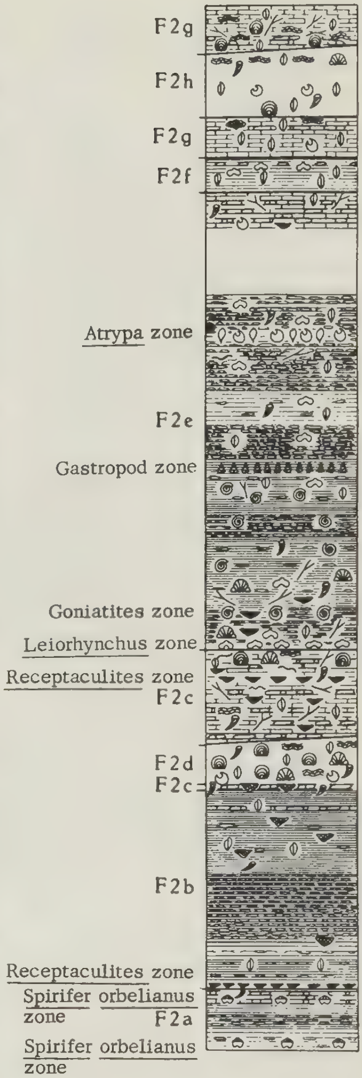


FIGURE 1. Section of limestone F2g in the railway cut southwest of Neuville Nord



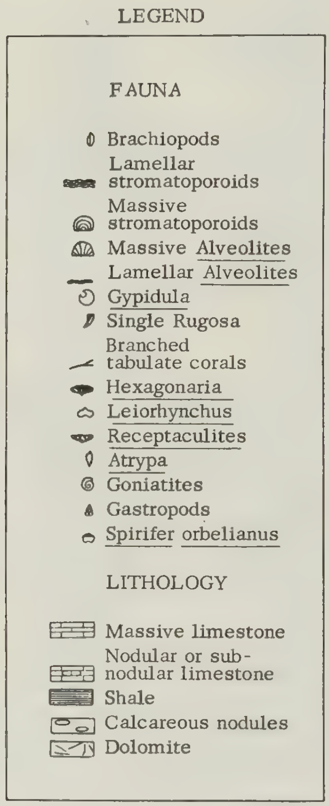


FIGURE 2. Cut of l'Ermitage road at Boussu-en-Fagne

Scale 0 25m

0 10m

NOTE: Towards the top of level F2b, above a density of approximately 5 m, a number of nodules omitted in the drawing should be added.

PLATE Va. Exploited "reef" F2j in the Croisettes and Grands Fonds quarries at Philippeville and Vodecée (see plates Vb and Vc)

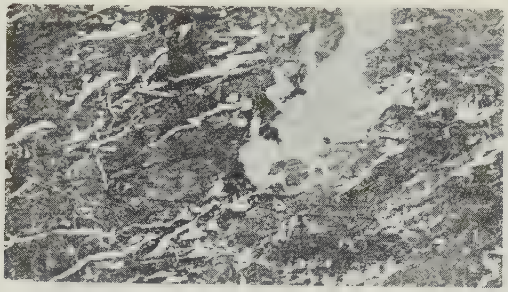


FIGURE 1. Ib. Lamellar coral zone (Alveolites and Acervularia)

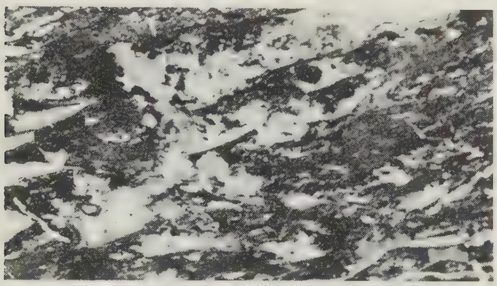


FIGURE 2. Ib. Upper section of this zone, calcite crystals appear toward the center; the figure shows a narrow colony of Alveolites, completely developed in height (0.40 m).

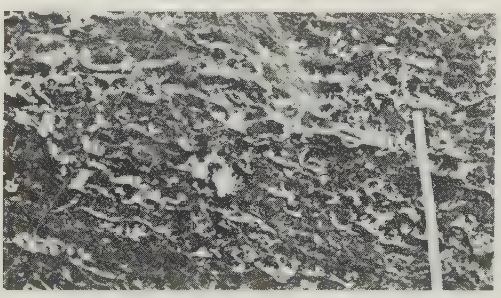


FIGURE 3. Ic. Area containing smalle Stromatactis, slightly anastomosed, connected to less numerous lamellar Alveolites The latter are visible toward the base.

PLATE Vb. Exploited "reef" F2j in the Croisettes and Grands Fonds quarries at Philippeville and Vodecée (see plates Va and Vc)

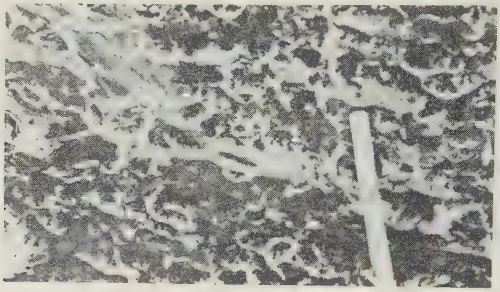


FIGURE 4. lc. Enlarged portion of the preceding photograph

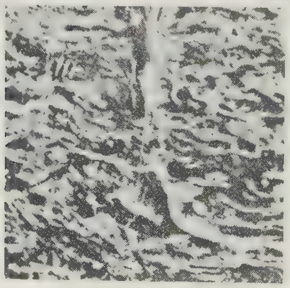


FIGURE 5. Upper section of the area containing large Stromatactis, greatly anastomosed

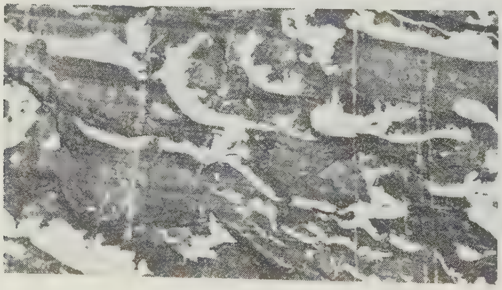


FIGURE 6. lc. Enlarged portion of the same zone, showing "terraces" cutting across the Stromatactis

PLATE Vc. Exploited "reef" F2j in the Croisettes and Grands Fonds quarries at Philippeville and Vodecée (see plates Va and Vb)

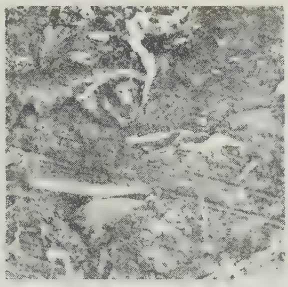


FIGURE 7. IIa. Trasnsitional zone containing large Receptaculites (two of them can be seen at the bottom) and scattered, irregular coralline colonies

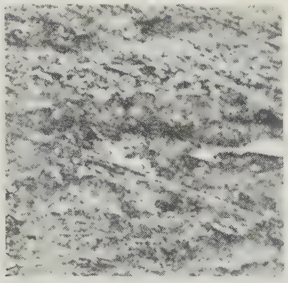


FIGURE 8. IIv. Area containing coral and brachiopods

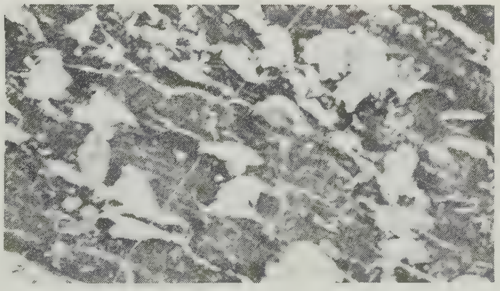


FIGURE 9. Exploited "reef" F2j in the Grands Fonds quarry at Vodecée The base of the middle zone (IIa) contains Receptaculites neptuni and large Heliophyllum helianthoides

PLATE VIa. Photographs of outcrops of Frasnian "reefs"

FIGURE 1. View of three superposed "reefs" at Tienne-devant-le-Village Frasnes-les-Couvin. The cliff visible in the foreground is the front of the Lion quarry.

FIGURE 2. View of four mushroomlike "reefs" on the Plateau des Hautes Fagnes between Mariembourg and Nismes

FIGURE 3. Lion quarry at Frasnes-les-Couvin. Indentations of stratified limestone F2g (to the right) in the limestone massif F2h (to the left)

PLATE VIb. Photographs of outcrops of Frasnian "reefs"

a) Shale F2f containing Xenocidaris mariaburgensis
b) Stratified limestone F2g
c) "Reef" F2h
d) Shale F2i containing Reticularia pachyrhyncha

FIGURE 4. Western extremity of "reef" F2h covered with stratified limestone F2g at the base (to the right) and silted (to the left) at the northern extremity of the l'Ermitage road, Boussu-en-Fagne

a) Shale F2i
b) "Reef" F2h
c) Stratified limestone F2g
d) Shale containing Xenocidaris mariaburgensis
e) Shale F2e containing Leiorhynchus formosus
f) "Reef" F2d
g) Stratified limestone F2c

FIGURE 5. View of the l'Ermitage elevation at Boussu-en-Fagne, showing two "reefs" F2h and F2d in superposition The two lower ridges visible in the foreground are limestone F2g (to the left) and F2c (to the right) surrounding a depression corresponding to shale F2e. These ridges proceed from one "reef" to the other in an east-west direction.

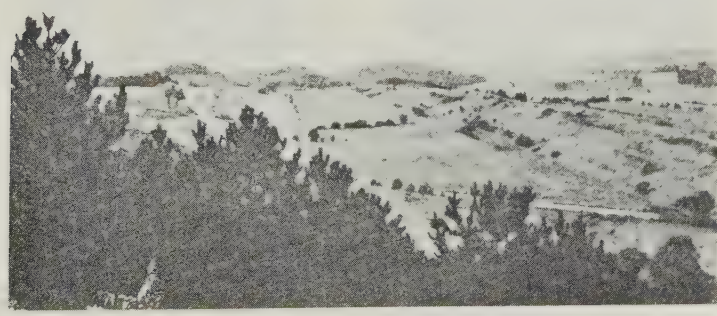


FIGURE 6. View of the interreefal zone with two ridges F2c (to the left) and F2g (to the right) west of the Boussu-en-Fagne "reef" The first two promontories visible in the background are (from right to left) "reef" F2h (Gros Tienne du By) and "reef" F2d (Hublet) which the two ridges emphasize.

ON PROSPECTING METHODS FOR BURIED DEVONIAN UPWARPS IN THE VOLGA REGION AT SARATOV [1]

by
Yu. P. Bobrov [2]
• translated by Salih Faizi •

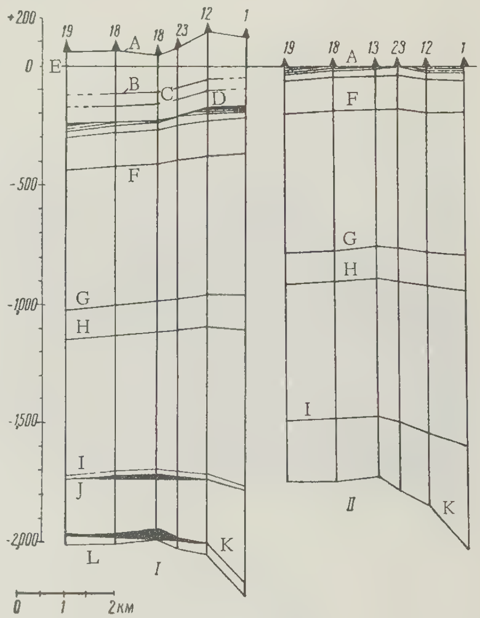
ABSTRACT

Above each oil-bearing Paleozoic upwarp in the D_2-V horizon of the Givetian in the Volga region at Saratov exists a zone of differential thickness of sediment due to pre-Bajocian erosion. Determination of variation in the thickness of Devonian and Carboniferous sediments overlain by younger strata may establish the position of these upwarps. Drilling programs have been designed for paleogeologic mapping in order to locate upwarps. Study of local and regional tectonic development also discloses thickness differentials. In places where the Bajocian sediments dip gently, paleogeologic maps may be replaced by less time-consuming paleostructure maps showing thicknesses from the bottom of the oil-bearing Myachkovsk horizon to the top of the Bajocian or eroded Carboniferous surface. In some prospective oil fields, such as the Surovka, seismic survey has failed to detect Devonian terrigenous strata and, consequently, paleogeologic mapping of the pre-Bajocian erosion surface is required. --G. E. Denegar.

The contact zone between the Middle Jurassic and Carboniferous sediments is one of the most significant stratigraphic unconformities in the Volga region at Saratov. All presently known oil deposits, such as the Sokolovogorsk, Guselka, and Atamanovsky fields, are the richest deposits of Paleozoic age and occur in the Nizhneshchigrovsk strata and in the D_2-V bed of the Givetian. The deposits are confined to the pre-Middle Jurassic upwarps of Devonian sediments. The positions of these upwarps are independent from the structural forms visible in outcropping Mesozoic sediments but can be established by plotting the points of reduced thicknesses of Devonian and Carboniferous sediments, unconformably overlain by Mesozoic and Cenozoic sediments (figs. 1-I and 2-I).

Areas where the thickness of the Paleozoic section decreases sharply because of the pre-Middle Jurassic erosion coincide with those where the thickness of the overlying beds remains constant. An inherited and repeated tectonic development which produced upwarps prior to Bajocian deposition is evident.

Because of the inherited tectonic development and the erosion of the upwarp crest during the Middle Jurassic transgression, the pre-Bajocian upwarps involving both the Devonian and Carboniferous sediments can be recognized only by the local reduction of the thickness, especially that of Carboniferous sediments below the Bajocian contact. At the crests of the pre-Bajocian upwarps, deeper horizons of Carboniferous and even Devonian sediments are exposed at the Bajocian contact, and the thickness of the Devonian sediments is reduced. On limbs of the upwarps, higher Carboniferous horizons are preserved below the Bajocian contact, and conse-

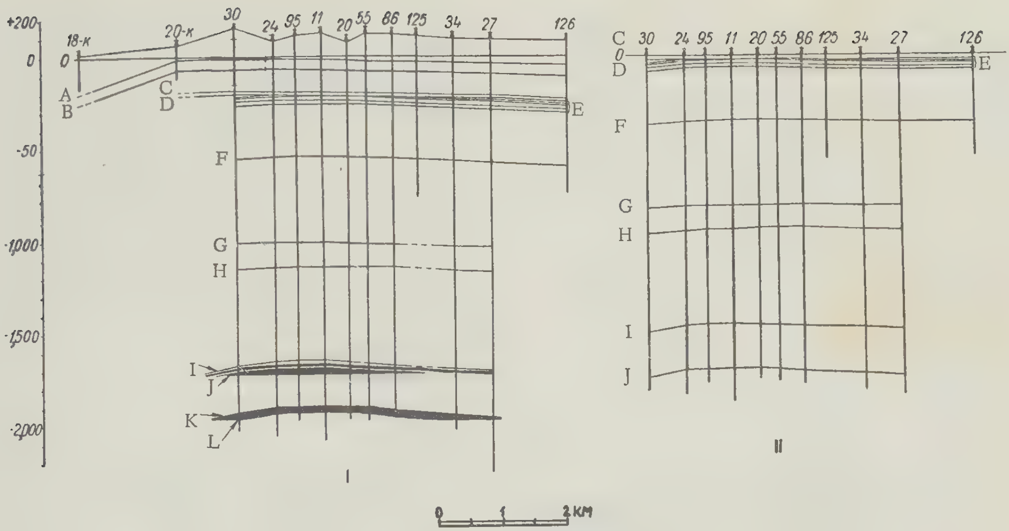


A - Old surface
B - Bathonian (top)
C - Bajocian (top)
D - Carboniferous (top)
E - Carboniferous limestone (erosion surface)
F - Podolsk (bottom)
G - Tulsk (bottom)
H - Devonian (top)
I - Verkhenshchigrovsk (bottom)
J - Nizhneshchigrovsk (oil deposit)
K - D_2-V bed of the Givetian (top)
L - D_2-V bed of the Givetian (oil deposit)

FIGURE 1. Cross section (I) along a-a of figure 6 and paleostructure sketch (II) at the beginning of Bajocian time, Guselka field

[1] Translated from O metodike pogrebennykh devonskikh podnyaty v Saratovskom Povlzhye: Novosti Neftyanoy Tekhniki, Geologiya, 1958, no. 8, p. 34-41.

[2] Scientific Research Institute of Geology, State University of Saratov.



A - Callovian (top)
B - Bathonian (top)
C - Bajocian basal sand (top)
D - Myachkovsk limestone (erosion surface)
E - Myachkovsk (beds 17-25)
F - Upper Bashkir (top)
G - Stalingrad (top)
H - Devonian (top)
I - Nizhneshchigrovsk (top)
J - Nizhneshchigrovsk (oil deposit)
K - D_2-V bed of the Givetian (top)
L - D_2-V bed of the Givetian (oil deposit)

FIGURE 2. Paleostructure sketch (I) and cross section (II) of the Sokolovogorsk upwarp

quently both the Carboniferous and Devonian sections are thicker (figs. 1-II and 2-II).

The directions in which the thickness of the Devonian section decreases coincide with those of the reduction of the Carboniferous strata because of the pre-Bajocian erosion. Thus, at the beginning of Bajocian time, the structural forms of Devonian and Carboniferous strata were identical.

The upwarps, which involved the Devonian sediments and formed both in Devonian and later but still in pre-Bajocian time, are of greater magnitude than those which deformed the Carboniferous sediments and were actually produced by pre-Bajocian tectonics. "The increase of the structural relief in the depth" is a characteristic feature of the Paleozoic [4].

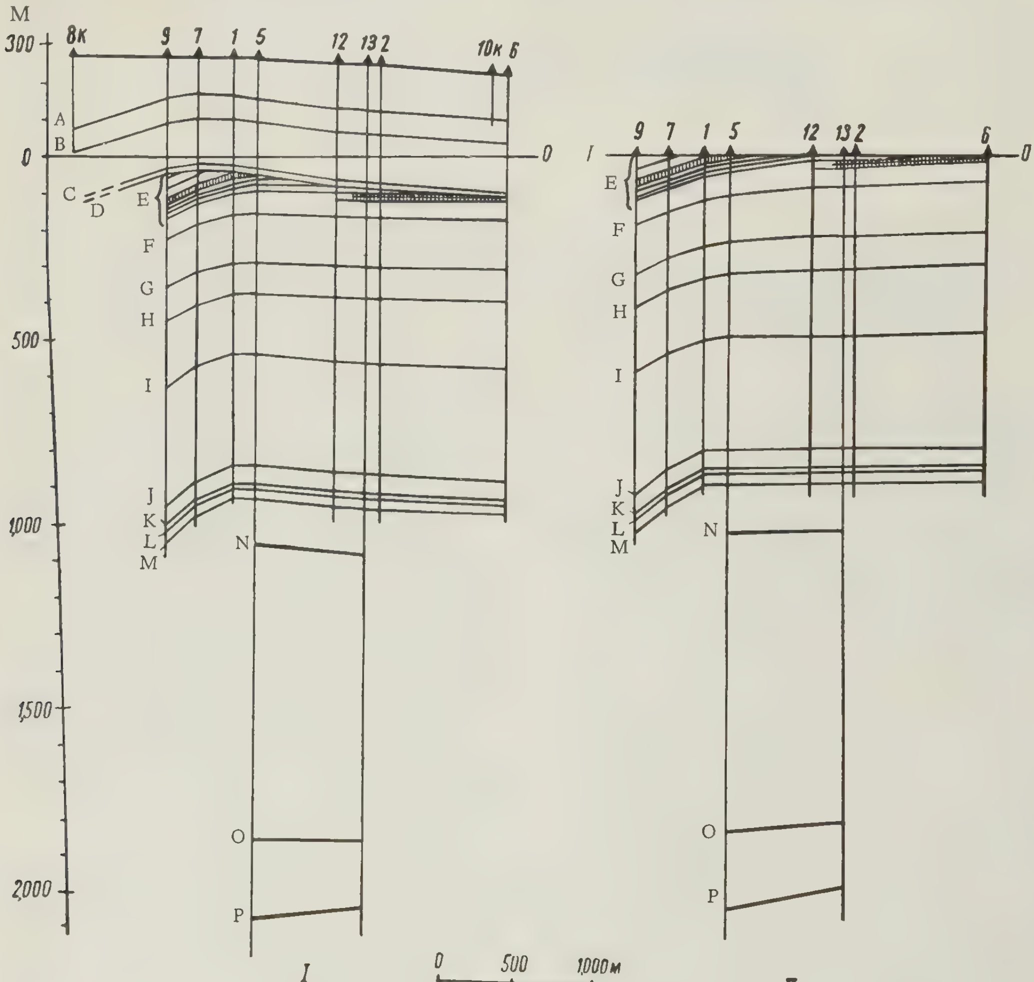
The nearly constant thickness of the Bajocian basal sands overlying the eroded Carboniferous (figs. 2-I and 3-I) (varies from 5 to 10 meters (m) depending on local upwarps) indicates an almost plane surface of the Carboniferous strata at the beginning of Middle Jurassic sedimentation.

The paleogeologic map of the eroded surface of Carboniferous before overlain by Middle Jurassic sediments was a map of cut-off beds [2, 3]. A map showing thickness variations of the eroded Carboniferous (Devonian) above one or another horizon up to the pre-Bajocian surface can, therefore, serve as a paleostructure map. The cross sections in which the pre-Bajocian erosion surface is taken as datum may actually serve as paleostructure cross sections of pre-Bajocian time. Such maps and cross sections give us an idea concerning the structural forms that existed in the Carboniferous and Devonian at the beginning of the Bajocian sedimentation. The contour map of the Carboniferous-Bajocian contact, which at the beginning of Middle Jurassic sedimentation was nearly a plane but is now folded along with Mesozoic strata, reveals the magnitude and locations of the post-Bajocian folds. On the other hand, the paleogeologic-structure map of the erosion surface truncating the Carboniferous discloses both the location of the pre-Bajocian upwarps and the type of post-Bajocian tectonics that altered the pre-Middle Jurassic structural forms.

The study of the paleogeologic-structure maps of the eroded surface of the Carboniferous made for the areas of local upwarps discloses that the crests of post-Bajocian structural elevations do not coincide with those of Paleozoic upwarps involving Carboniferous and Devonian strata and existed prior to the Bajocian sedimentation [1]. The core of younger elevations is usually displaced toward the steeper limb of the pre-Middle Jurassic upwarps. The disconformity of the position of the structural elements of the two tectonic systems indicates a change in the orientation of tectonic forces. Because of the superimposed post-Bajocian tectonics that displaced the core of the local structural elevations the pre-Bajocian structural forms involving terrigenous Devonian and Carboniferous strata were

altered (fig. 1-I). The pre-Bajocian upwarps involving the Carboniferous became basically changed in form, but their core composed of terrigenous Devonian sediments and having greater magnitude preserved their positions. Consequently, the present structural elements involving the Carboniferous do not reflect the exact form of the pre-Bajocian structural elevations involving the terrigenous Devonian.

In the Volga region at Saratov above each Paleozoic upwarp having oil deposits in the D_2-V horizon, or in the Nizhneshchigrovsk strata, a zone exists where the stratigraphic depth of the pre-Bajocian erosion increase locally, as can easily be seen on the paleogeologic map of the eroded top of the Carboniferous stratum. In order to reveal the oil-bearing upwarps in the terrigenous Devonian, a special drill program for mapping purposes was suggested in 1956 of an area considerably larger than those where the oil wells are currently being drilled in the Paleozoic production horizons, with which drilling data a paleogeologic map of the eroded surface of the Carboniferous could be made.



A - Callovian (top)
B - Bathonian (top)
C - Bajocian basal sand (top)
D - Myachkovsk limestone (erosion surface)
E - Upper Myachkovsk (beds A-H, at Bajocian contact)
F - Podolsk (top)
G - Vereisk (top)
H - Upper Bashkir (top)
I - Lower Bashkir (top)
J - Tulsk (top)
K - Stalingrad (top)
L - Cherepetsk (top)
M - Upinsk (top)
N - Devonian (top)
O - Givetian (top)
P - D_2 - V bed of the Givetian (top)

FIGURE 3. Cross section (I) and paleostructure sketch (II) at the beginning of Bajocian time, Surovka upwarp

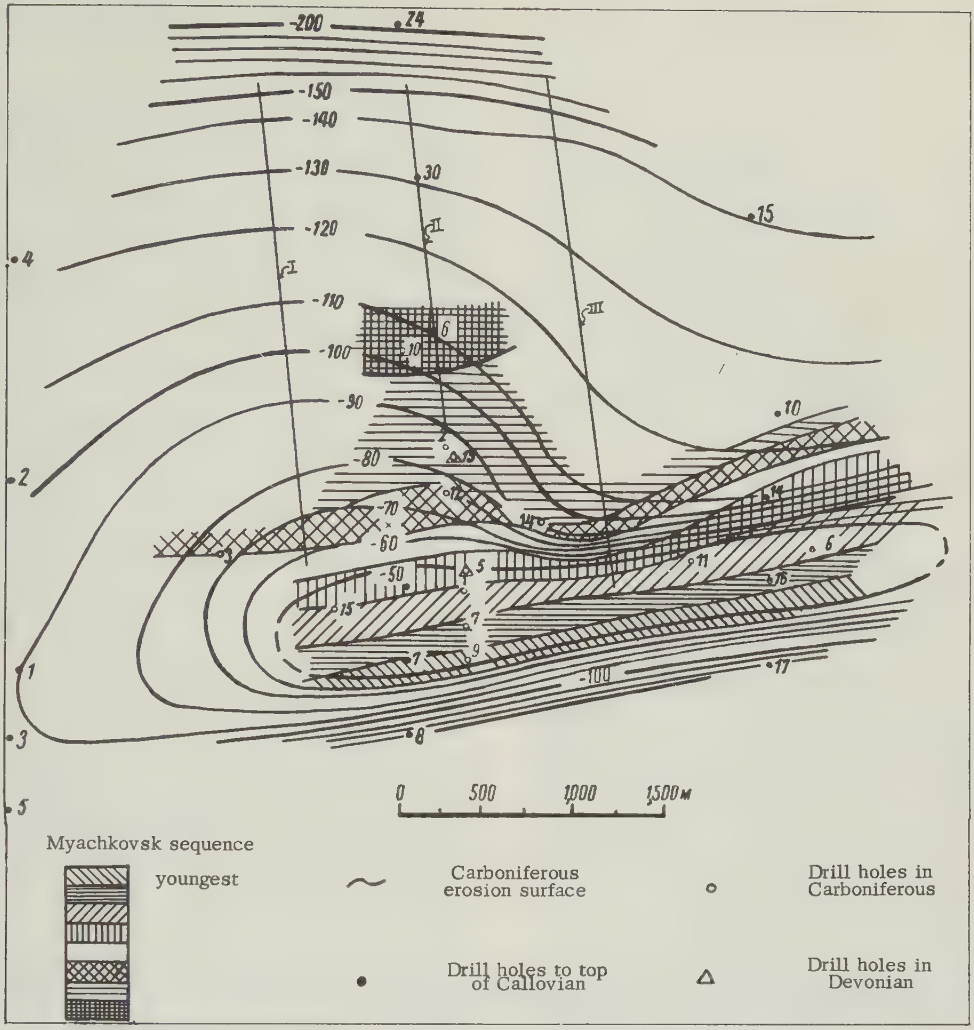


FIGURE 4. Structure-paleogeographic map of the Surovka upwarp on the erosion surface of the Carboniferous

A tectonic study in the Surovka field disclosed the existence of an old upwarp at the beginning of the Bajocian time and apparently begun as early as in Devonian, as can be assumed according to drill hole 13p, which reveals reduced thickness in the Devonian sediments (figs. 3 and 4). The southern limb of a nearly east-trending upwarp was steeper in the area of drill holes 15p, 9p, 1p, and 4p, but due north it becomes more gentle near the crest of the upwarp. As a result of a superimposed post-Bajocian upwarp, which is well pronounced on the contour map on the eroded top of the Carboniferous strata, the southern limb of the pre-Bajocian upwarp was elevated, forming an upwarp known as the Surovka structural elevation (fig. 5).

The post-Bajocian deformation was strong enough to fold the pre-Bajocian limb into an upwarp involving the Carboniferous; the position of the latter upwarp, as can be seen, for example, on the top of the Stalingrad horizon, is determined by post-Bajocian tectonics. However, the magnitude of the post-Bajocian tectonics was not adequate to reconstruct the southern limb of the old upwarp at the top of the D_2-V bed, as seen in drill holes 5p and 13p. At the beginning of the beginning of Bajocian time, the top of the D_2-V bed was 75 m higher at drill hole 13p than at 5 p, while the altitudes of the Stalingrad level differ 10 m at the same drill holes and the amplitude of the post-Bajocian tectonics may be 25 m vertically. Because of this, the D_2-V bed is 40 m higher in drill hole 13p, located on the northern limb of the Surovka upwarp, than in drill hole 5p located at the crest of the same upwarp involving the Carboniferous. The post-

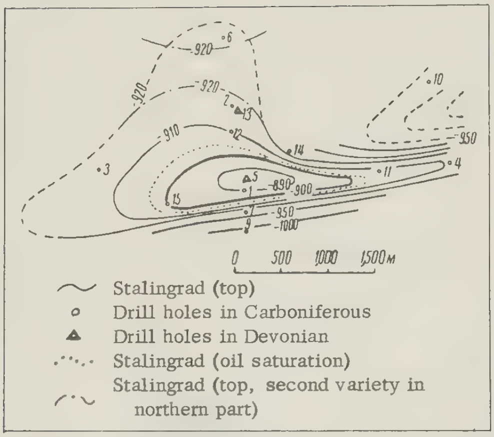


FIGURE 5. Structure map of the Surovka upwarp on the top of the Stalingrad

Bajocian tectonics dropped at drill hole 13p for 35 m relative to that at drill hole 5p. Thus, the still higher altitude of the D_2-V bed at drill hole 13p is a result of the pre-Bajocian tectonics.

An examination of the paleogeologic-structure map of the Surovka field and of cross sections through it, which demonstrate the structure at the contact zone between the Jurassic and Carboniferous, reveals that due north, toward the crest of the pre-Middle Jurassic upwarp of Carboniferous sediments, the stratigraphic depth of pre-Bajocian erosion increases. The stratigraphic depth of the Carboniferous horizons cropping out at the pre-Bajocian erosion surface increases progressively from south to north, while the angular unconformity between the Jurassic and Carboniferous sediments decreases in the same direction to drill hole 12p. Between drill holes 9p and 1 p, the angle of the unconformity is 8^{o}; between 1p and 5p, 6^{o}; between 5p and 12p, 3^{o}; and, finally, between drill holes 12p, 13p, and 2p, no angular unconformity is evident but only a stratigraphic disconformity. Farther north, the angular unconformity is again 1.5^{o} between drill holes 2p and 6p; this conforms with the elevation of the Carboniferous horizons at drill hole 6p.

The altitude of the top of the D_2-V bed, elevated at drill hole 13p by pre-Bajocian tectonics and the stratigraphic disconformity between the parallel lying Carboniferous-Jurassic strata, reflecting the form of an old structural terrace [Tr.: structural nose?] and possibly the overbending of Carboniferous horizons, permit us to assume that near this hole there had been the axis of an old structural elevation that had been deformed in the Givetian and had retained its position without being essentially altered by the post-Bajocian tectonics. The exact position of the axis is difficult to determine. However, a sharp southerly turn of the contact of the "B" and "C' beds on the paleogeologic map suggest that the crest of the upwarp is somewhere northeast of drill hole 2p.

In the Sleptsovka field, north of the Surovka field, stratigraphically higher horizons of the Carboniferous stratum crop out at the pre-Bajocian erosion surface than in drill hole 6p of the Surovka field. In the Sleptsovka field, the paleogeologic map reveals a pre-Bajocian monocline with beds dipping to the south. This proves the existence of a syncline somewhere between the two fields. The structure in the Sleptsovka field is still little known: perhaps a system of small upwarps separated by gentle saggings or a single large monocline exists.

The complexity of the pre-Bajocian structures within the well-drilled fields west of the Volga river, such as in the region of Kurdyumo-Yelshansk fields where several independent upwarps existed early in Bajocian times in the Sokolovogorsk, Guselka, Pristannoye fields, and others [1], permits us to assume that if the bending of beds produced a large structural element, this was complicated by local upwarps, most likely comparable in their extent with other pre-Jurassic upwarps well known west of the Volga river. Several upwarps of this size could be located between the Surovka and Sleptsovka fields.

The Surovka field, where no seismic data is available, must be drilled by a set of special holes to provide data for a paleogeologic-structure map of the pre-Bajocian erosion surface in order to clarify the buried upwarps of Devonian and Carboniferous strata and only afterward can its results be used to continue deep drilling into the Devonian. The work can be reasonably accelerated if drilling starts simultaneously along three lines marked I, II, and III in figure 4 and continues according to the results obtained. The drill holes along the lines must not be farther apart than in 500- to 750 m.

The holes must be drilled to the 2-m thick bed at the bottom of the Myachkovsk horizon, which is easily recognizable, in order to correlate the Carboniferous limestones cropping out at the Bajocian contact. The depth of this bed from the pre-Bajocian erosional surface decreases due north. For example, in drill hole 9 it is 180 m deep; in drill holes 1, 5, 12, 2, and 6 it is 120, 100, 80, 80, and 60 meters deep, respectively. Along the lines I, II, and III, the depth of the bottom of the Myachkovsk horizon from the top of the Carboniferous stratum apparently will not exceed 60 to 80 m.

In places where the Bajocian sediments dip gently, the paleogeologic maps may be replaced by the less time-consuming paleostructure maps showing the thicknesses from the bottom of the Myachkovsk horizon to the top of the Bajocian basal sands or to the eroded Carboniferous surface.

The Surovka field is not the only prospective field where seismic survey failed to detect Devonian terrigenous strata, and, consequently, paleogeologic mapping of the pre-Bajocian erosion surface is required. The exploration experience in the Guselka, Yuzhno-Pristanskaya, and Trofimovka fields (fig. 6), where a large number of exploration holes are currently drilled into the Devonian stratum, demonstrates that the launching of such holes only upon the data of seismic surveys without preliminary study of the paleogeology of the pre-Bajocian erosion surface leads to great unproductive drilling.

For example, in the Trofimovka field the experimental seismic survey of 1954 to 1955 and the experimental-methodic study reached the Paleozoic only to the Frasnian; the position of upwarps in the Givetain remained undisclosed. New exploration holes (drill hole 10) are being drilled here in a southern direction, in which Mesozoic and Carboniferous horizons are deeper and the depth of the pre-Bajocian erosion surface also increases.

At present, when seismic survey fails to detect the Devonian terrigenous strata, we cannot rely completely on geophysical methods in our efforts to prepare new fields for exploration in the Volga region at Saratov, for the number of readily discovered upwarps is small here. The seismic survey must be supplemented by shallow drilling for mapping purposes, for these two methods supplement each other and permit us to drill deep exploration holes into the Devonian with greater confidence in success.

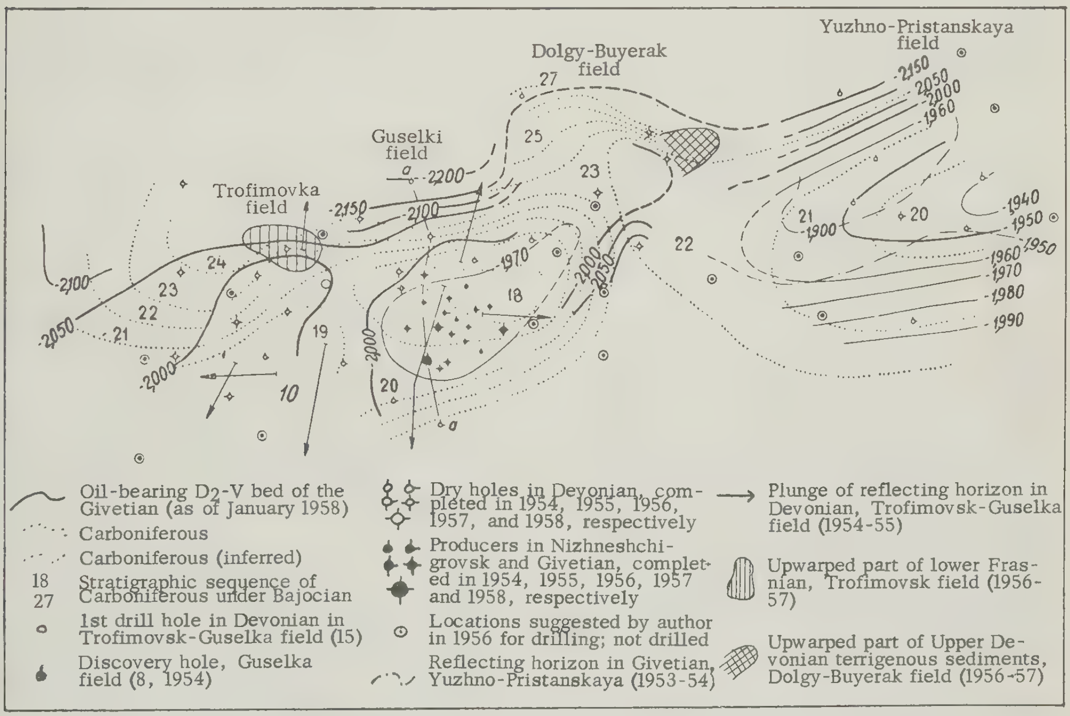


FIGURE 6. Comparison of structure map on the top of the D_2-V bed of the Givetian with the paleogeographic map of the eroded Carboniferous surface and seismic data

REFERENCES

1. Bobrov, Yu. P., PERSPEKTIVY I METODIKA POISKOV DREVNIKH NEFTENOSNYKH PODNYATY NA TERRITORII SARATOVSKOGO PRAVOBEREZHYA [PERSPECTIVE AND METHODS OF EXPLORING FOR ANCIENT OIL UPLIFTS IN THE SARATOV AREA]: Novosti Neftyanoy Tekhniki, Geologiya, 1957, no. 2.

2. Brod, I. O., and Ye. I. Frolov, POISKI I RAZVEDKA NEFTYANYKH I GAZOVYKH MESTOROZHDENY [EXPLORATION AND RECONNAISSANCE FOR OIL AND GAS DEPOSITS]: Gostoptekhizdat, 1957.

3. Mirchink, M. F., NEFTEPROMYSLOVAYA GEOLOGIYA [GEOLOGY OF OIL PRODUCTION]: Gostoptekhizdat, 1946.

4. Uspenskaya, N. Yu., NEKOTORYYE ZAKONOMERNOSTI NEFTEGAZONAKOPLENIYA NA PLATFORMAKH [SOME PRINCIPLES OF OIL AND GAS ACCUMULATIONS ON PLATFORMS]: Gostoptekhizdat, 1952.

GAUSSBERG, ANTARCTICA[1]

by
O. S. Vyalov and V. S. Sobolev[2]
• translated by L. Drashevska •

ABSTRACT

Gaussberg is composed of basaltic lava in which pillow structure is locally developed. The lava is a leucite basalt, not similar to rocks found within the Antarctic continent and subantarctic islands. The lava is black, scoriaceous, and without visible mineral-grain outlines. The walls of bubble cavities are lined with black volcanic glass.

The southern slope of Gaussberg is covered with small volcanic bombs or lapilli which exhibit traces of rounding of originally sharp edges. Glacial moraines contain boulders of various granites, gneisses, and schists, specifically amphibolite, biotite-garnet schist and gneiss, leucocratic biotite gneiss, granite gneiss, alaskite granite, Rapakivi-type granite, and pegmatite.

The freshness of the exposed lavas, in addition to glacial boulders found at the top of the volcanic cone, indicate that the now extinct Gauss volcano was formed before the Glacial epoch, possibly in the Pliocene.

The optical constants of the principal rock-forming minerals supplement Reinisch's petrographic description of the Gaussberg lavas. Petrographic data and chemical composition indicate that the lava is an intermediate leucite basalt. A comparison of the diopside-leucite-silica equilibrium system and the values obtained in this study place the temperature of the lava between 1, 150° and 1, 200°C. --T. F. Rafter, Jr.

INTRODUCTION

Gaussberg, Antarctica, was discovered in March 1902 by the German expedition led by E. Drygalski during the cruise of the Gauss in 1901-1903 [14]. Members of the expedition compiled a topographic map of the mountain on the scale 1:7, 500 which was published in Drygalski's article [10]. This report also included some photographs. E. Philippi conducted a geologic investigation of the mountain. His work [13] is the only existing description of the general geology of this area. R. I. Reinisch studied the petrology of samples brought from the mountain and presented a detailed description of the leucite basalts and included xenoliths of Gaussberg [14].

Late in 1912, Gaussberg was visited by the western sledge party of the Australasian Antarctic Expedition under Sir Douglas Mawson. The party consisted of three men, one of whom, K. Godley, was a geologist. Results of this party have not been published except for a general description of the journey by Mawson after S. Johnes' data [11]. S. R. Nockoldes studied the petrology of some of the samples collected, mainly of those from the moraine [12].

On February 21, 1956, during his stay in Antarctica, O. S. Vyalov visited the mountain. (On February 20, 1956, Vyalov left Mirnyy station in a small AN-2 airplane piloted by A. A. Kash with I. P. Kucherov's astronomic group. The airplane landed 4 kilometers (km) from the mountain on a badly crevassed ice surface. The next day, Vyalov climbed the mountain with the pilot and radio technician, A. I. Chelyshev.) It was possible to make geologic observations only along the route of ascent. In a few hours, rock samples of both the mountain and moraines were collected. (A rusty metallic can was found on the eastern summit of Gaussberg. In it was a note, dated December 16, 1912 [Tr. : There is a mistake in the date: the Australasian party visited Gaussberg on December 24-26, 1912.], left by the Australasian group. The note was written in pencil on a sheet of heavy drawing paper; it was well preserved.) L. V. Klimov studied samples from the moraine; V. S. Sobolev made petrographic studies of the bedrock.

This article presents the results of these investigations.

GENERAL DESCRIPTION

Gaussberg is a rather regular volcanic cone composed of leucite basalts. It is located on Wilhelm II Land, on the coast of Davis Sea, near the margin of the continental ice sheet.

The black cone of Gaussberg is the only local

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[1] Translated from Gora Gauss v Antarktike: Izvestiya Vysshikh Uchebnykh Zavedeny Geologiya i Razvedka, 1958, no. 2, p. 3-17.

[2] Ivan Franko Lvov State University.

projection above the seemingly endless ice. This is the only exposure on the coast of Davis Sea to the west of Mirnyy settlement and Adams Islet. The continuous white surface of the continental ice sheet stretches from this point southward. The next outcrop is more than 200 km southwest; this is Brown Mountain, which, according to the data of the Antarctic Expedition of the Academy of Sciences of the U. S. S. R. of 1957, is 2, 133 m above sea level and 150 m above the ice surface. According to B. P. Parkhatov, this mountain is composed of Precambrian crystalline rocks predominantly granites and gneisses.

The Drygalski expedition [10] established coordinates of Gaussberg as follows: lat 66°47' 48" S. ; long 89°18'45" E. (from Greenwich).

This recently extinct volcano is located within the ancient Eastern Antarctic platform. Its foundation is composed of gneisses, schists, and granites; charnockites are common and comprise the islands in the area of Mirnyy settlement [2, 3, and 4]. Besides Gaussberg, Recent volcanos are known to occur on the Antarctic platform only on the eastern coast of Victoria Land and on the adjacent islands in the Ross Sea. One of them, Mt. Erebus, is active now.

A high submarine ridge stretches over the bottom of the Indian Ocean toward the coast of the Davis Sea. It passes through the Gribb Bank, Heard Islands, and Kerguelen Islands, and is known in the literature as the submarine Kerguelen Ridge, or the Kerguelen-Gaussberg Ridge. Some workers are inclined to associate this ridge with the young geosynclinal zone. We think, however, that the Kerguelen-Gaussberg Ridge and other submarine ridges bordering the eastern Antarctic are Recent, probably even Quaternary, elevations associated with vertical movements [4].

The northern slope of the mountain drops directly to the sea; the eastern, western and southern slopes are under the continental ice sheet. Elevations of the ice surface gradually increase southward and are near the southern coast, as high as 130 m above sea level.

The summit of the mountain resembles a narrow ridge with a length of about 150 m, stretching in a north-northwest direction and having two elevations at the ends. According to the data of the Drygalski expedition, the height of the western elevation is 370. 6 m, that of the eastern elevation is 369. 9 m [10]. Mawson [11] presents another value, namely 1, 148 feet (349. 9 m) which is repeated in the British sailing directions [15]. This value should be considered too low.

The astronomic group of our expedition found the elevation of the western part of the ridge to be 373 m [11], the depression in the ridge between its western and eastern ends not more than 5 m, and the cross section of the base of the mountain about 1. 5 km.

Gullies of low relief on the slope of the mountain result in some undulation of the cone contours [11, table 1]. The southern slope alone is characterized by two well-developed gullies divided by a distinct ridge, along which Vyalov ascended the mountain.

An interesting peculiarity of the mountain is the presence at several levels of even terraces. Vyalov saw one such narrow platform about 100 m long on the ridge between two gullies. The remains of a cairn were found there, evidently the trigonometric point D of the Drygalski expedition which was set up at an elevation of 234. 4 m [10, table 1]. Another terrace shelf could be clearly seen from the summit. It is located on the northern slope at about the same elevation, and is from 50 to 70 m wide. Another similar ledge occurs a little below the summit ridge. Philippi and Drygalski described a number of terraces at different elevations: 1) 330-340 m, 2) 230 m, 3) 150 m, 4) 100 m, and 5) 70 m. Three lower terraces of the southern slope were observed during the ascent of the mountain, although they are hardly noticeable.

The literature presents two different interpretations of the origin of these flat terraces. Philippi holds their formation is a result of external processes and not to be associated with structural peculiarities of the volcanic cone. Each terrace corresponds to a halt in the general ice retreat. The formation of the terraces is explained by different degrees of weathering: it was less intense under the ice which covered the terraces and was much more intense above the ice sheet. In other words, the subaerial weathering acted more quickly than the subglacial weathering [13]. Drygalski is of another opinion. He notes the absence of the ancient morainal deposits on the surface of the terraces and advances a number of other arguments against the Philippi theory. He thinks that the main terraces represent initial individual lava flows which were later somewhat reworked by moving ice. He considers that there was no cessation of movement during the ice retreat. The terraces were formed only at the end of the ice recession and resulted in the formation of one lateral and two coastal moraines which are located at the northwestern foot of the mountain [10].

Because our observations were very brief and we saw only a few such terraces, we refrain from any opinion on this question. However, we observed a smooth surface at a height of about 230 m on the ridge dividing the two gullies, which hardly can be considered to be a remnant of an individual flow. Another argument against this interpretation can be found in the development of a similar terrace at about the same elevation in different points on the slopes of the mountain.

The same can be said about the highest smooth surface at an elevation of 330-340 m. It is hard to assume the formation of several flows on different slopes just at the same elevation. Therefore we are inclined to ascribe the appearance of the landforms under discussion to glacial erosion. It may be that the formation of the terraces is due to recent oscillatory movements and to marine abrasion, but there is no proof of this.

The mountain is composed of basaltic lava in which pillow structure is developed in places. As established already by Reinisch [14], the lava is leucite basalt, a category of very rare rocks. To our knowledge, no rocks of similar composition have been found within the Antarctic continent and subantarctic islands.

Macroscopically the lava is black and scoriaceous; no outlines of mineral grains are visible. The walls of the bubble cavities are lined with black volcanic glass. The lavas are widely exposed near the mountain summit and appear to be very fresh here. A cracked crust is observed on the lavas (fig. 1). Somewhat lower, on the southern slope, the lava outcrops are covered by small fragments and in the lower portion of the slope they completely disappear under debris.

Small rock fragments on the slopes consist almost exclusively of lava. As observed on the southern slope, these rocks commonly appear not as split fragments, but as small volcanic bombs or lapilli (fig. 2). They are not spindle shaped, but bear traces of rounding of the sharp edges which most likely occurred not from mechanical processes, but in the process of lava solidification. Usually their surfaces are rough. Somewhat rounded fragments appear to be of a lighter color than angular ones. Tuffs seldom occur [13]; we collected none.

Small fragments of native sulfur are found in places near the summit. We also found sulfur veinlets and inclusions which already had been described by Philippi. Nests of such inclusions produce insignificant concentrations of sulfur detritus.

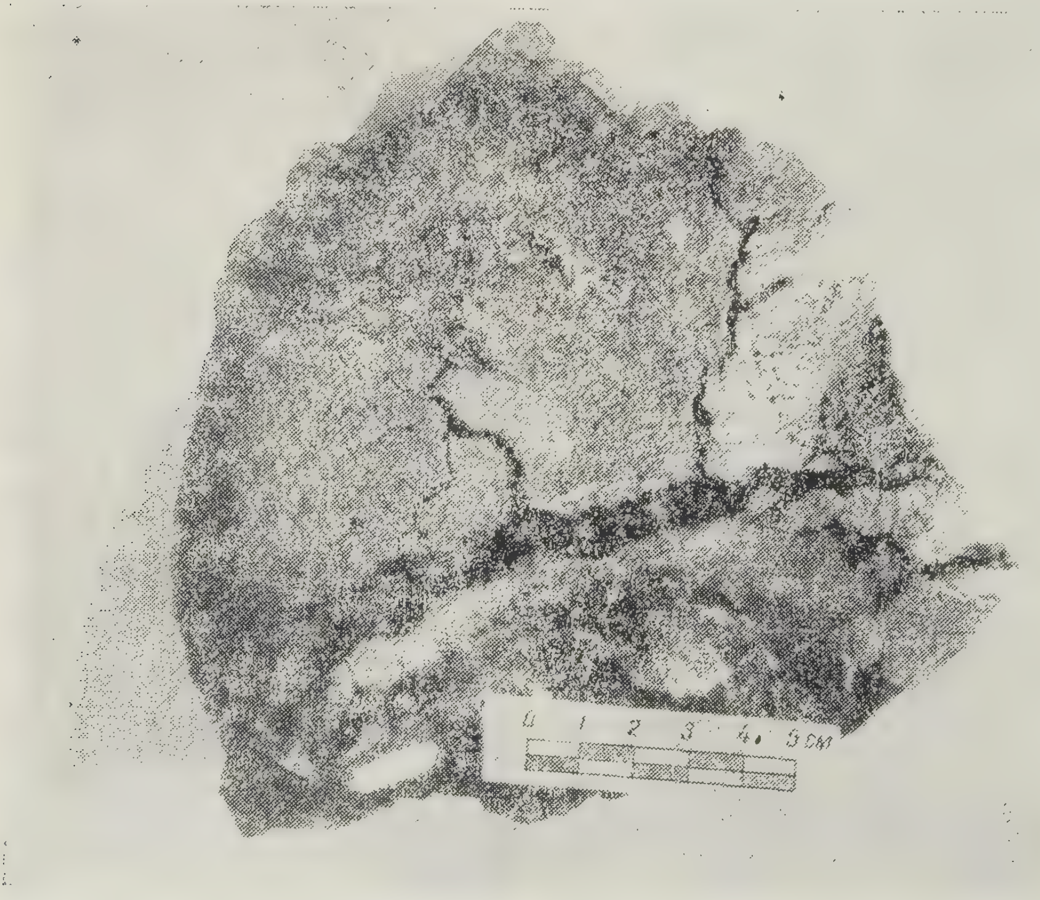

FIGURE 1. Lava with cracked crust

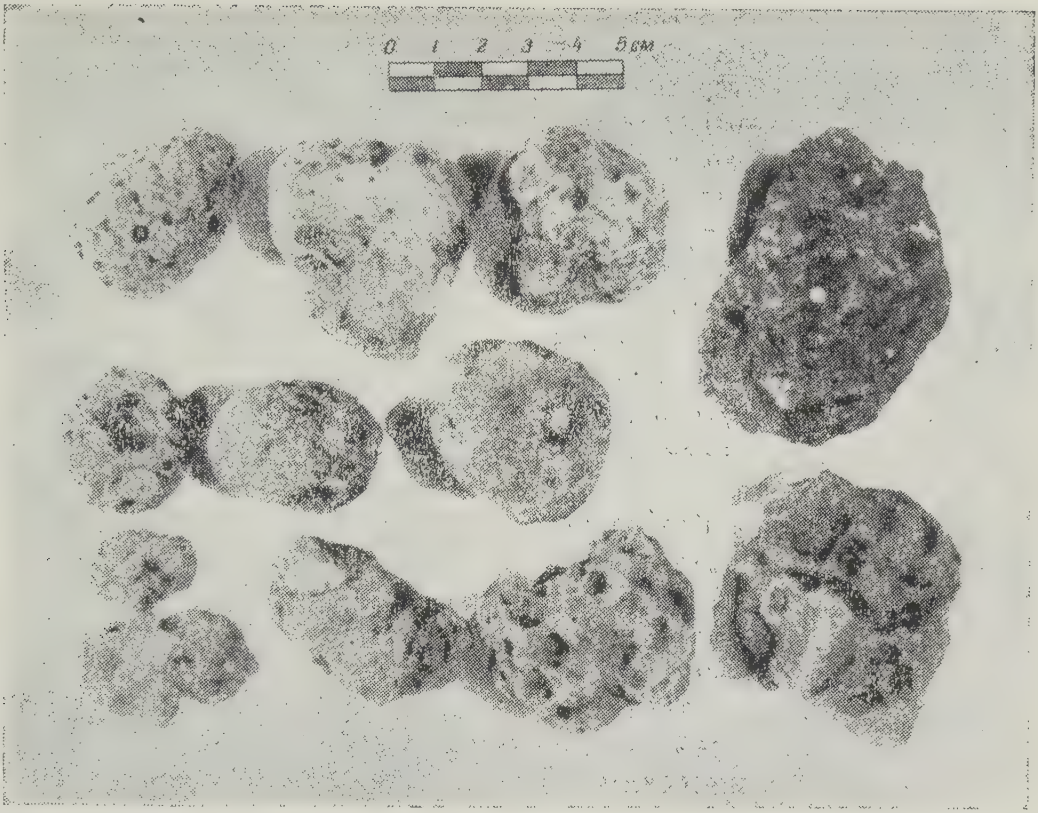

FIGURE 2. Lapillilike fragments of scoriaceous lava

Rounded and elliptical, granular inclusions with cross sections up to 15 cm frequently occur. These are baked xenoliths which are differentiated from the lava by distinct boundaries. In the walls of these boundaries are found small white crystals. The xenoliths found by Philippi and described by Reinisch are of a rather homogeneous compostion. All (in Reinisch's collection and in ours as well) show traces of melting. They are altered granites and pyroxene gneisses, and are of interest in that they give a basis for conclusions on the composition of rocks of the Precambrian crystalline basement.

A white efflorescence of salt was observed on the summit and in the top section of the northern slope (We did not descend far down the northern slope). Such an efflorescence is present in great amounts in the Bunger Hills. No doubt this efflorescence results not from chemical weathering of rocks, as was sometimes considered, but rather from salts from the sea.

Philippi is right in his assumption that snow storms bring salty snow. When sea water freezes under extreme low temperature, its salts crystallize on the surface of newly formed ice. During snow storms, these small crystals, together with the snow, are caught up and carried by the wind [13, p. 63].

An accumulation of morainal material is found at the southern foot of the mountain. It is here mixed with bedrock fragments (basalts) which have rolled down the steep slope. Some boulders encountered in the moraine are 1 m in diameter. According to Drygalski's and Philippi's data, a rather narrow morainal belt extends all along the southern foot. They also recorded morainal deposits in some places at the eastern, western, and northwestern bases of the mountain.

On the southern slope we observed a line of moraines with knobs up to 0.5 m at an elevation of from 10 to 12 m. This line stretches to both sides, encircling a part of the mountain. Between this line and the very summit, a few boulders occur with diameters of from 20 to 40 cm, but the bulk of the boulders are smaller than this. Boulders consist of different granites, gneisses, and schists. In our collection, the study of which has not been completed, Klimov found amphibolite, biotite-garnet schist and gneiss, leucocratic biotite gneiss, granite-gneiss, alaskite granite, Rapakivi-type granite, and pegmatites. Philippi mentions the presence of quartzite sandstones

and conglomerates [13, p. 60], and Nockoldos writes of metamorphic limestones from the K. Godley collection of 1912 [12]. As noted by previous workers [10 and 13], the presence of glacial boulders at the summit of Gaussberg, at an elevation of about 370 m, is of great interest and significance.

First of all, this gives a basis for the conclusion that in the earlier period of glaciation, the mountain was covered by ice, which was at least 400 m thicker than the contemporary ice sheet. This gives some basis for an estimate of the age of the volcanic cone.

The very character of the lavas, their freshness, as well as the regular conical form of the mountain indicates a recent age. Philippi considers that Gauss volcano was active at the end of the Tertiary period [13, p. 70]. Mawson refers to this mountain as a comparatively recent, but extinct volcanic cone [11, p. 327], which information is repeated in the British sailing direction [15, p. 307].

Because glacial boulders are found at the very top of the volcanic cone, it was probably formed prior to the epoch of glaciation. As correctly noted by Philippi, the composition of xenoliths is very homogeneous; these xenoliths were derived from the ancient foundation, not from diverse morainal deposits. It is possible that Gauss volcano is of Pliocene age; in any event, it was formed before the Glacial epoch. No indications of erosion were observed on the lavas, such as polished surfaces and striae. Evidently they disappear rapidly as a result of weathering.

Photographs by Philippi and Hazert [13, tables II and III] reveal that even in April the northern slope of the mountain was not covered by snow at all; at the end of September the slope was only slightly powdered by snow, although in places snowdrifts occur. On the western slope, tremendous snowdrifts are observed which in places extend almost to the summit (in April). In winter, the southern slope is probably completely covered by snow [13, table III, fig. 1]. During our visit, we saw small patches of snow near the summit. Some patches were seen on the northern slope. There was much more snow on the southern slope and the two previously mentioned gullies were almost completely filled with snow.

We have said that the northern slope of the mountain passes directly into the sea. Water was seen in the crevasses of the fast ice.

Viewing the country from the mountain summit on February 21, 1956, we saw a strip of ice with a comparatively even surface and width of about 300-500 m which extended directly north far into the sea; only a few small icebergs were observed within this strip. This strip was bordered on both sides by continuous fields of compacted tabular icebergs, some of them with smooth surfaces, and some with crevasses; they were steeply inclined, some of them were even in an upright position. From the mountain summit, fast ice and icebergs were seen in the sea stretching toward the horizon in all directions. No doubt the icebergs were formed somewhere in this locality. Looking east, one could clearly see the nature of the ice cover as it extends from the mountain. Near the mountain, the ice surface was almost smooth; somewhat farther, large parallel crevasses occur; and, still farther, the surface was broken by numerous crevasses both parallel to the edge and perpendicular to it. Also, the ice masses, future icebergs, could be seen which had partially separated from the continental ice sheet along crevasses but were still connected with it. Other masses had completely separated and even moved into the sea, but remained connected by the fast ice. The same phenomenon was observed on looking west from the mountain: the ice masses coming down into the sea and broken by crevasses, as well as by iceberg fields. However, still farther west they were evidently connected into a continuous field - the Western Shelf Glacier. The exact edge of this glacier, could not be distinguished under the conditions of light at the time of the observation, between 5 and 6 p. m.

Directly south from the mountain a flat, comparatively even, ice surface covered by snow gradually rises southwards. A distinct depressed strip extends along the very foot of the mountain. Evidently this is a thawing groove, formed as a result of solar heating of the adjacent bedrock. Water produced by summer thawing of snow percolates down through the talus onto the southern slope of the mountain. Thawing had already ceased at the time of our visit. Small smooth ice surfaces were observed, evidently formed as a result of the freezing of small water accumulations. It should be added, that is was a sunny day when we visited the mountain, the rocks were not cold, and heated air currents were visible above the black slope.

Between the mountain and the campsite, a distance of 4 km from the foot of the mountain, where the airplane was landed, lies a zone of very long and wide snow-covered crevasses. They can be detected by the fact that the snow over them is darker than elsewhere. On the route from the campsite to the mountain, a seemingly bottomless crevasse was seen. The snow cover was on one side of the crevasse 30 cm thick, and on the other side, about 1 m thick.

The crevasses in the eastern section are oriented almost due north, gradually turning more and more to the northeast. Towards the west, the crevasses have a northeastern direction, but they are intensely winding. No bend was seen between the continental ice sheet proper and the shelf-ice border in the south. However, this bend was distinctly visible in the east. A similar bend was also seen to the west. We may

consider that the bending of the ice masses is a reflection of the character of the bedrocks and marks the edge of the continent. If a relation between the bends observed in the east and those in the west is assumed, the connecting line should run somewhat to the south from the campsite on the flat surface facing the mountain.

Gaussberg is probably an island connected with the continent only by the shelf glacier. Fauna is very poor here. In the course of our excursion, we saw only a few skuas and one Wilson petrel. Australian explorers observed a few skuas, Antarctic petrels, and Wilson petrels [11, p. 272]. No penguins were found here.

At several points along the slope and near the summit, some lichens were collected; near the base of the southern slope, an accumulation of fresh-water algae was found. These collections are being studied now by the Botanical Institute of the Academy of Sciences of the U. S. S. R.

OUTLINE OF PETROGRAPHY OF GAUSSBERG

It has been stated that Reinisch [15] presented a detailed petrographic description of interesting lavas of the Gauss volcano collected by the Drygalski expedition. Nockoldos who studied the materials of Mawson's Australasian expedition refrained from presenting any additions, referring to the previously made descriptions [12]. We now have an opportunity to supplement the above description by adding the optic constants of the principal rock-forming minerals. This gives the basis for drawing conclusions on their chemical properties. We shall not repeat here details of morphology of the mineral as given by Reinisch, but mainly shall take from his work the chemical characteristics of the rocks. In the description of xenoliths in the basalts some implications concerning the temperature of the lava will be presented.

The lavas of the Gauss volcano are classified as typical leucite basalts on the basis of mineral composition. Their structure is porous and even scoriaceous to greater or lesser degree; the texture is aphanitic and microporphyritic. Phenocrysts of olivine, monoclinic pyroxenes, and leucite occur in a groundmass of glass, leucite, monoclinic pyroxene, ore minerals, and some biotite and hornblende.

Olivine occurs in the rock in quantity, dominating the monoclinic pyroxene. The olivine grains show a typical habit for the rocks described, some show traces of melting at edges (fig. 3). The olivine grains and phenocrysts of other minerals are very small, usually between 0.1 and 0.6 mm. Refractive indices measured in immersion mediums: Ng = 1.700, Np = 1.664. (Measurements of refractive indices were made by Ye. A. Kostyuk.) This corresponds [1] to a content of 14 percent fayalite component. 2V

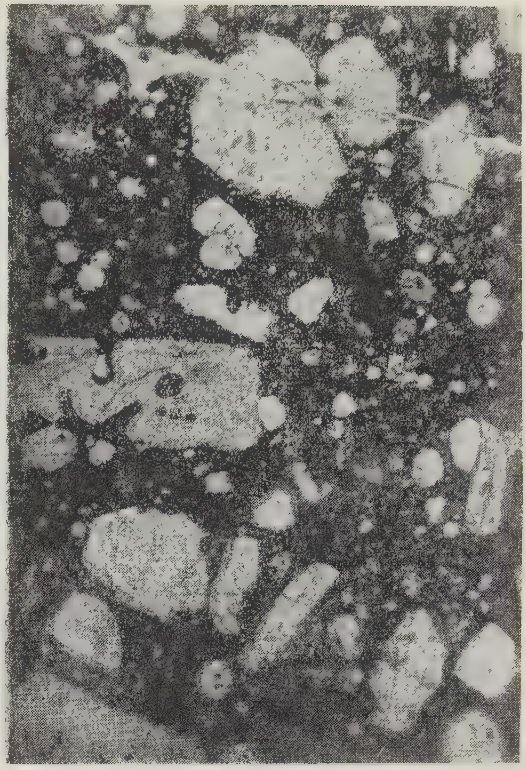

FIGURE 3. Leucite basalt. Olivine phenocrysts, some with melted rims, are seen, as well as phenocrysts of leucite and monoclinic pyroxene. Magnification 80, without analyzers.

measured on the Fedorov universal stage varies from 89° in the central portions of the grains to 85° in the marginal parts, which respectively correspond to a 14 and 25 percent fayalite content. As is usual in similar rocks, olivine in Gaussberg basalt is poor in iron, although the fayalite component in the marginal part of crystals is somewhat greater.

Monoclinic pyroxene contains fewer porphyritic phenocrysts than olivine. It is usually represented by characteristically elongated prisms. Twinning is common; sometimes indistinct zoning is observed. Ng = 1.702, Np = 1.676, 2V ranges from +65 in the center to +55 at the margins of the grains, c : Ng = +42+43°.

These data indicate the low iron content of pyroxene and that this pyroxene does not belong to the pigeonite series of pyroxenes characteristic of basaltoids richer in silica. The application of the conventional curve from the series of diopside-hedenbergite curves shows that the content of the iron is 12 to 15 percent. Considering even the small amount of iron oxide, the corresponding percentage should be considered still lower.

Concerning the presence of Chermak's components in the investigated pyroxene, it can be stated that the small angle c:Ng and the comparatively low refractive index show that the content of trivalent iron is very small. From A. I. Tsvetkov's diagram [8], we see that the maximum possible content of the component $CaFe_2SiO_6$ is less than 5 percent. Tsvetkov's data show, in fact, that in pyroxenes of complicated composition the optic constants do not enable the determination of the component $CaAl_2SiO_6$. It may be assumed by analogy with other similar rocks that augite rich in aluminum is present in the $CaAl_2SiO_6$ in the order of 10 to 15 percent.

In one place, an olivine phenocryst was found partly surrounded by augite; this shows a later crystallization of monoclinic pyroxene than olivine. The intergrowth is evidently regular and the 010 face of pyroxene coincides with the 001 face of olivine, the 001 face of pyroxene approximately coincides with the 010 face of olivine.

More leucite than femic minerals is present in the rocks. The size of leucite phenocrysts are up to 0.5 mm in size, and their crystals have a characteristic form. Leucite is nearly isotropic or has a very slight birefrigence, hence twinning is usually hard to distinguish. Greater birefrigence was found in leucite of basalts in which the groundmass has a higher degree of crystallization. Typical skeletal leucite crystals, as described by Reinisch, were not found in our rocks. Glass inclusions are rare (fig. 4).

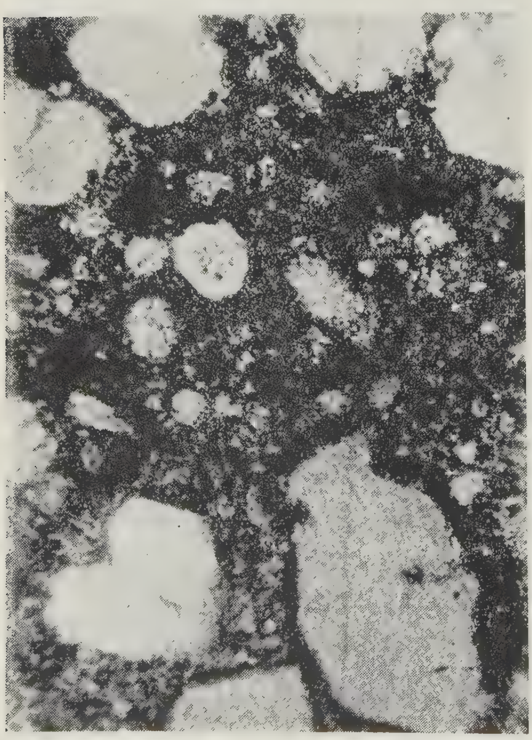

FIGURE 4. Leucite basalt. Zoning within distribution of inclusions is seen in small leucite crystal. Magnification 200, without analyzers.

The groundmass in some cases is almost exclusively glass (porous lava) having a refractive index of 1.574 which corresponds [7] to a silica content of about 51 percent. Only minute (about 0.01 mm long) leucite crystals were found in this glass. Crystals were observed to be of sizes intermediate between the groundmass and the phenocrysts. There is very little pyroxene. In basalts with a higher degree of crystallization, in addition to leucite crystals, comparatively many thin needles of monoclinic pyroxene are present in the groundmass (fig. 5). The refractive index of glass is of a smaller value here; in one case it was measured to be 1.567. There is almost no difference between the refractive index, Ng = 1.706, of the monoclinic pyroxene in the groundmass and that of the pyroxene phenocrysts.

In basalts with pure glass, the pyroxene needles of the groundmass are occasionally replaced by light-brown hornblende (apparently barkevite) which in some cases resembles augite but differs from it in extinction angles, in a regular orientation relative to monoclinic pyroxene, and in a larger value, $2V = 50\text{-}60^{\circ}$ of the angle. In basalts with a higher degree of crystallization of the groundmass, many biotite scales and minute particles of ore minerals are found in the glass. Unexpectedly, a rather high refractive index was obtained for biotite of orange-brown color; it lies within 1.652 to 1.674. There is no doubt that this increase in the value of the refractive index is associated not with a general high iron content, but with the presence of the oxylepidomelane component and of titanium. Reinisch indicates a large optical angle in biotite, $2V = 36\text{-}40^{\circ}$. Only very small (0.01 to 0.05 mm) biotite scales, mostly xenomorphic and more rarely, idiomorphic plates, were found in our samples. There is no doubt that biotite and hornblende were crystallizing when the glass was already solidified; the crystallization evidently occurred due to the action of volcanic gases. Side by side with irregular grains of ore minerals, there occur also plates with elongated cross sections, evidently of ilmenite.

Walls of large bubble cavities, up to 5 mm and more in cross section, are usually lined with a thin (up to 0.5 mm) crust of glass. At the contact with the rock, glass contains in places needles of brown hornblende which lie approximately perpendicular to the contact; less frequently biotite scales occur.

Table I presents data on the chemical composition of rocks from Gaussberg (after Reinisch).

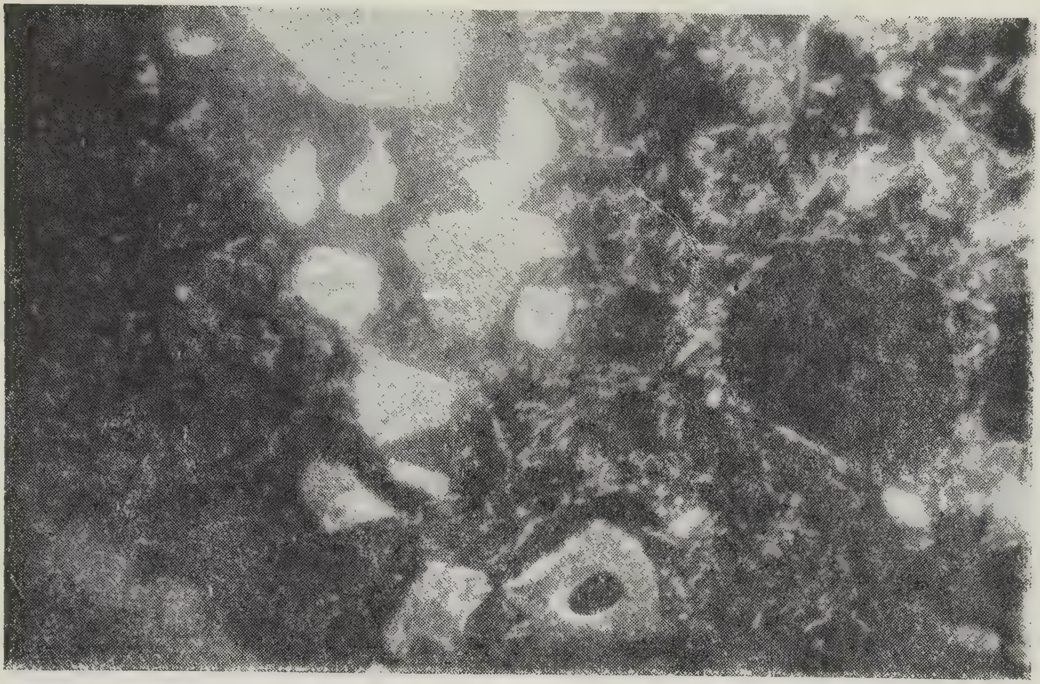

FIGURE 5. Leucite basalt. Phenocrysts of olivine, monoclinic pyroxene, and leucite. Anistropy and repeated twinning are noticeable. Small pyroxene needles are seen in the groundmass. Magnification 80, crossed nicols.

TABLE 1. Chemical composition of leucite basalts from Gaussberg

Major oxides	Average of four analyses of leucite basalts (after R. Reinisch)	Composition of vitreous crust (after R. Reinisch)	Average for leucite basalts (after Daly)	Average for leucites (after Daly)
SiO_2	50.69	48.71	46.18	46.90
AlO_3	14.55	13.26	12.74	16.33
FeO_3	6.69	7.35	5.27	4.22
FeO	3.00	6.02	5.06	4.14
MnO	-	-	0.19	0.11
MgO	6.39	5.89	8.36	5.03
CaO	5.07	4.65	8.16	9.72
Na_2O	1.88	2.10	2.36	2.75
K_2O	8.95	9.96	6.18	7.58
H_2O	1.04	1.34	2.13	1.22
FiO_2 [sic]	1.51	0.36	0.77	0.50
P_2O_5	0.86	1.02	2.60	1.50
Total	99.72	100.66	100.00	100.00

TABLE 2. Characteristics of chemical composition (after A. N. Zavaritsky)

Number	a	c	b	s	f'	m'	c'	n'	Q
1	16.7	1.2	24.4	57.7	33.5	42.3	24.2	24.2	19.2
2	17.5	1.2	25.7	55.5	40.4	38.0	21.6	18.4	25.2
3	13.8	1.5	31.5	53.2	29.7	44.0	26.3	37.0	22.7
4	17.1	2.5	25.6	54.8	29.5	33.5	37.0	35.5	27.1

For comparison, Daly's data [5] on average leucite basalt and average leucite are given. Table 2 presents A. N. Zavaritsky's characteristics.

It has been indicated by Reinisch [14] that leucite basalts from Gaussberg are characterized by a high silica content. The content of potassium oxide is also high, which leads to a considerable silica deficiency and to high negative value of Q. Correspondingly, the value of b is much decreased. The value of c also remains very low, and the second analysis even gave a negative value. Among the values of secondary importance in Zavaritsky's characteristics, let us indicate first of all some increase in the value of c'. The value of f' is rather high, the same as has been indicated for the average composition of the rocks; this should be ascribed to the presence of iron oxide in the ore mineral and in glass; the femic minerals, as has been stated, are poor in iron.

The data lead to the conclusion that our rock is closer to intermediate leucite. However, the value of c' is here much lower than that even in intermediate leucite basalt as seen in the low content of pyroxene (table 1 and 2).

The study of the interrelation between mineral grains showed that undoubtedly olivine was first to crystallize and soon was followed by leucite. Reinisch presented interesting sketches showing that leucite began to crystallize later. At the end of the intertellurian stage, the crystallization of olivine ceased and was replaced by the crystallization of pyroxene. It is known that reactive interrelations between olivine and pyroxene are typical for pyroxenes of the pigeonite series; at the same time, an eutectic scheme of crystallization takes place in the case of olivine and diopside. However, in our more complicated system, reactive relations were common at the last stage of the crystallization; in particular, this is confirmed by a complete absence of olivine in the groundmass. Iron and magnesium accumulated in the residual magma. During the last stage of the crystallization there occurs either the formation of brown hornblende, which replaces pyroxene, or the crystallization of biotite, together with ore minerals; this evidently depends on the oxygen supply. Neither hornblende nor biotite are typical for the groundmass of effusive rocks. In rare basic rocks, similar to our leucite basalts, the crystallization of these minerals is possible after the effusion of lava on the earth surface.

During the late stage of phenocryst crystallization of the groundmass (before the formation of hornblende and biotite) we have a simultaneous segregation of leucite and monoclinic pyroxene. Reclaculating the second analysis, and leaving out olivine and the ore mineral, we obtain approximately: leucite, 68 percent, pyroxene, 27 percent, and silica, 5 percent. Thus, figure 6 shows that in the system leucite-diopside-silica [9] the point of the diagram is located in the leucite field and rather far from rocks rich in silica. It is understandable that after the crystallization of a considerable amount of leucite, the point of residual magma will come to the cotectic line diopside-leucite. The crystallization temperature of such magma should be only a little lower than 1,300° C, but evidently it is much lower in comparison with the theoretical scheme because of the presence of iron.

Reinisch indicated that there are two types of xenoliths in basalts: those of holocrystalline rocks which were brought from great depths and whose origin was in some way associated with leucite basalts, and xenoliths of acid rocks from the Archeozoic basement in which the volcanic channel was located.

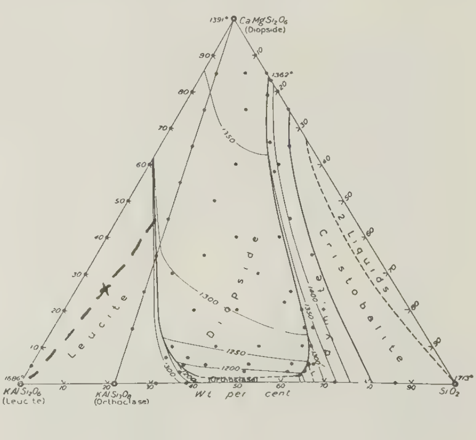

FIGURE 6. Anorthite-leucite-silica [Ed.: Diopside-leucite-silica] system according to Schairer and Bowen [7]. "X" marks the approximate position of leucite basalt from Gaussberg.

Among xenoliths of the first type, the ultrabasic rocks of lherzolitic composition were found, as well as inclusions composed of leucite and monoclinic pyroxene. Lherzolite xenoliths contain rhombic pyroxene; therefore, they are not in equilibrium with the magma of given composition. They are of interest, since they attest to the genetic connection of the magma of leucite basalt with the body of ultrabasic rocks; later a considerable change in the magma composition evidently occurred.

Minerals of pyroxene-leucite inclusions correspond to those in the phenocrysts of the rock, but they cannot be glomeroporphyritic clusters as no olivine is found in them. Apparently they represent some related homogeneous bodies formed somewhere at depth during the differentiation of the same magma. The above inclusions were not found among the rocks of the described collection.

The xenoliths of the second type, engulfed by the lava in the volcanic channel from Archeozoic rocks, were present in our collection in a considerable amount. Our studies give a basis for some considerations concerning the temperature of lava at the moment of effusion.

The following minerals are usually present in these xenoliths: quartz, microcline, plagioclase, and monoclinic pyroxene; probably rhombic pyroxene also occurs locally. Measurements of plagioclase indicate andesine-labradorite up to 50 percent, sometimes a zonal one, up to oligoclase 22 percent in the rim. Pyroxene is usually completely destroyed and full of very fine inclusions of ore minerals and other secondary products. Opaqueness is found in plagioclase only near the zone which underwent melting, especially near pyroxene, as well as in the rim of acid plagioclase. Beyond the boundary of glass, most of the plagioclase and microcline appears completely fresh.

All the xenoliths investigated have marked traces of melting and contain secondary glass. It is clearly seen that glass was formed only at contacts between the different minerals, first of all at the contact between quartz and other minerals: microcline, plagioclase and pyroxene, and also between pyroxene and feldspars. The values of refractive indices of glass are different in different sections of the rock. In sections, the glass between quartz and feldspars is light with a refractive index between 1.492 and 1.498. Its composition corresponds to that of usual eutectic glass of liparites. The glass formed near the pyroxene is darker and is characterized by a higher refractive index, 1.517 to 1.537. Newly formed needles of pyroxene are found in the glass; needles grow in directions perpendicular to the boundaries of parts of the minerals which underwent melting (fig. 7). The values determined for pyroxene are Ng = 1.737, Np = 1.710; thus, this pyroxene is quite different from that

FIGURE 7. Inclusions in leucite basalt In the glass at the contact with destroyed pyroxene (black field), newly formed pyroxene needles and round pores are seen. Magnification 200, without analyzer.

in basalts which contains about a 60 percent iron. Reinisch indicates that small grains of spinel were formed in the glass.

The width of strips of glass between the minerals measures 0.2 to 0.5 mm. Bubbles are found in places in the glass. Individual glass veinlets are emplaced in minerals along minute fissures. In the plagioclase having an oligoclase composition of 20 to 25 percent in the rim parts of some grains, thin veinlets and drops of glass are observed; this indicates the beginning of the melting of this mineral.

Concerning the temperature of magma which swallowed the xenoliths, let us consider the corresponding temperatures of melting of eutectics of two-component systems: potassium feldspar-quartz 1,030° and albite-quartz 1,015° [5]. There is no doubt that the temperature of the lava was much higher than the above values, because distinct marks of melting are seen at contacts of corresponding minerals. The plagioclase is not albite, but plagioclase up to 50 percent andesine-labradorite, which should raise the temperature of melting of the eutectic with quartz by at least 100 degrees. The appearance of drops of glass in plagioclase having a composition of oligoclase of 20-25 percent indicates that the temperature was more than 1,150°. However, microcline

in the xenoliths, which was not in contact with quartz, were not altered; the temperature was below 1,200°. The narrow range of lava temperature was between 1,150° and 1,200°; these values are lower than the temperature of melting of the eutectic diopside-leucite-silica.

CONCLUSIONS

Gaussberg is a volcanic cone of regular form. This volcano is built of leucite basalts and was formed late in the Tertiary, or early in the Quaternary period. The lava temperature was between 1,150 and 1,200°. The last solfatara stage of activity was characterized by the appearance of a small amount of native sulfur. The Precambrian foundation in the Gaussberg area is composed mainly of Archeozoic pyroxene granites and pyroxene gneisses; this can be stated on the basis of the study of the composition of the xenoliths.

Gaussberg is probably an island connected with the continent by means of the ice sheet. At the time of the Glacial epoch, the thickness of the ice sheet was greater by at least 400 m, and it projected far into the sea.

Lavas from Gaussberg differ greatly from all other lavas known on the Antarctic continent, as well as on subantarctic volcanic islands; the latter lavas also belong to the type of alkaline rocks rich in potassium.

REFERENCES

1. Winchell, A. N., OPTICHESKAYA MINERALOGIYA [OPTICAL MINERALOGY]: INO, 1949 [New York, 1937].

2. Vyalov, O. S., K GEOLOGII RAYONA STANTSII MIRNY [ON THE GEOLOGY OF THE MIRNYY STATION AREA]: Akademiya Nauk SSSR, Izvestiya, Seriya Geologicheskaya, 1957, no. 6, [International Geology Review, v. 1, no. 6, June 1959 (in English)].

3. __________, KRATKOYE OPISANIYE POBERZHYA A MORYA DEVISA I KHARAKTERISTIKA RAYONOV BUKHTY DEPO I MIRNOGO [BRIEF DESCRIPTION OF THE SHORE OF DAVIS SEA AND THE CHARACTERISTICS OF THE MIRNYY STATION AREA]: Geografichesky Sbornik, no. 4, Lvovskogo Gosudarsvennogo Universiteta, Lvov, 1957.

4. __________, PREDVARITELNYYE DANNYYE PO GEOLOGII POBEREZHA ANTARKTIDY MEZHDU 89 I 107° V. D. [PRELIMINARY DATA ON THE GEOLOGY OF THE ANTARCTIC COAST BETWEEN LONGITUDES 89° AND 107° E.]: Geologichesky Sbornik Lvovskogo Geologicheskogo Obshchestva, 1957, no. 4, [International Geology Review, v. 1, no. 5, May 1959 (in English)].

5. Zavaristsky, A. N., VVEDENIYE V PETROKHIMIYU IZVERZHENNYKH GORNYKH PORОD [INTRODUCTION TO THE PETROCHEMISTRY OF EFFUSIVE VOLCANICS]: Akademiya Nauk SSSR, Izvestiya, 2-c, 1950.

6. __________, IZVERZHENNYYE GORNYYE PORODY [EFFUSIVE VOLCANICS]: Akademiya Nauk SSSR, 1955.

7. Lodochnikov, V. N., GLAVNEYSHIYE PORODOOBRAZUYUSHCHIYE MINERALY [PRIMARY ROCK-FORMING MINERALS]: Izvestiya, 4-e, Gosgeoltekhizdat, 1955.

8. Isvetkov, A. I., IZOMORFNYYE ZAMESHCHENIYA V GRUPPE BESSHCHELOCHNYKH PIROKSENOV [ISOMORPHIC SUBSTITUTION IN ALKALI-IMPOVERISHED PYROXENE]: Akademiya Nauk SSSR, Institute Geologicheskikh Nauk, Trudy, 1951, v. 138.

9. Bowen, N. L., THE SYSTEM SiO_2 - DIOPSIDE-LEUCITE: Amer. Jour. Ser., v. 33, 1937.

10. Drygalski, E., DER GAUSSBERG, SEINE KARTIERUNG UND SEINE FORMEN. DEUTSCHE SUDPOLAR EXPEDITION 1901-1903 [GAUSSBERG, PREPARATION OF ITS SURVEY SHEET AND FORM. GERMAN SOUTH POLE EXPEDITION 1901-1903]: Geologie und Geographie, v. 11, no. 1, 1906.

11. Mawson, D., GEOGRAPHICAL NARRATIVE AND CARTOGRAPHY, AUSTRALASIAN ANTARCTIC EXPEDITION 1911-1914: Scientific Reports, ser. A, v. 1, Sydney, 1942.

12. Nockoldos, S. K., PETROLOGY OF ROCKS FROM QUEEN MARY LAND, AUSTRALASIAN ANTARCTIC EXPEDITION 1911-1914: Scientific Reports, ser. A, v. 4, Geology, pt. 2, Sydney, 1940.

13. Philippi, E., GEOLOGISCHE BESCHREIBUNGE DES GAUSSBERGES. DEUTSCHE SUDPOLAR EXPEDITION 1901-1903 [GEOLOGIC DESCRIPTION OF GAUSSBERG, GERMAN SOUTH POLE EXPEDITION 1901-1903]: Geologie und Geographie, v. 11, no. 1, 1906.

14. Reinisch, R. I., PETROGRAPHISCHE BESCHREIUNG DER GAUSSBERG-GESTEINE. DEUTSCHE SUDPOLAR EXPEDITION 1901-1903 [PETROGRAPHIC DESCRIPTION OF GAUSSBERG. GERMAN SOUTH POLE EXPEDITION 1901-1903]: Geologie und Geographie, v. 11, no. 1, 1906.

15. Anon., THE ANTARCTIC PILOT: 2d ed., London, 1948.

A CONTRIBUTION TO THE GEOCHEMISTRY OF RESERVOIR FORMATIONS: THE LOWER FRASNIAN OF THE VOLGA-URALS [1] (Part 3 of 3)

by

N. M. Strakhov, K. F. Rodionova, and E. S. Zalmanzon

• translated by Mark Burgunker •

THE DISTRIBUTION OF IRON, MANGANESE, PHOSPHORUS, AND TRACE ELEMENTS IN THE LOWER FRASNIAN OF THE VOLGA-URALS PROVINCE

(by E. S. Zalmanzon and N. M. Strakhov)

Materials and Methods

Ninety-one samples from the lower Frasnian were geochemically analyzed for iron, manganese, phosphorus, and trace elements. The stratigraphic and lithologic distribution of the samples is as follows: 7 sandstone, 17 siltstone, 19 clay, 12 marl, 14 argillaceous limestone, and 9 limestone and dolomite samples from the Pashysky and sub-Domanik; 1 clay, 6 marl, 3 argillaceous limestone, and 3 limestone and dolomite samples from the Domanik. All were treated with hydrofluoric acid to which insoluble soda had been added. The soda was reduced in the presence of metallic bismuth during determination of the iron concentration [2]. This method is extremely simple and makes it unnecessary to reduce the iron with hydrogen sulfide or mercuric chloride; no loss in precision of determination is involved. The manganese concentration was determined colorimetrically after the manganese had been oxidized with persulfate. Phosphorus was determined by weight (De Vault's method) after two precipitations in a magnesium mixture. The concentrations of all other elements were determined colorimetrically.

The vanadium and chromium concentrations were determined in aqueous solution after extraction from a soda melt by means of the methods developed by Sandell [51] and Vinogradov [8]. Colorometric determinations for vanadium were made with phosphortungstic acid and for chromium with diphenyl carbazide. For determinations of copper concentrations, samples were treated with hydrofluoric acid; the insoluble residue was fused (this method was developed for trace-element determinations in the Petroleum Geology Institute - IGN). Copper concentrations were determined by means of Shakhkeldian's hydrogen sulfide method [48]; this method also requires colorimetric analysis with potassium cyanide. We used orthotolidine [13] in our colorometric experiments. This method gives bright shades of blue and is more sensitive than Shakhkeldian's. Dimethyl glyoxyl was used in the colorimetric determination of nickel. The extraction and oxidation of nickel were made by the method developed by Gulyayeva [12]. Cobalt content was determined by the pyrophosphate-thiocyanogen method developed by Zvenigorodskaya [19].

Spectrographic analyses and semiquantitative determinations were made for all elements with which the investigation was concerned. The tables presented in this paper contain the results.

Distribution of Iron in the Lower Frasnian of the Volga-Urals Province

Examination of the distribution of iron in lower Frasnian sediments indicates rigorous petrographic control of the concentrations of this element. The following relationships are obtained from comparison of mean concentration values in table 67: 1) the concentration of elementary iron increases sharply as the mean diameter of the clastic particles decreases (passing from the sandstones to the siltstones and clays); 2) the iron concentration in the pelitic clastics depends upon the amount of carbonate material present, and decreases as the latter increase; 3) the presence of a large amount of organic matter does not seem to affect the concentration of elementary iron in any way. There is reason to suspect that an increase in the amount of organic matter may entail a slight decrease in the iron concentration. In any event, the amount of organic matter does not seem to affect the iron concentration in either the coarse-grained or the fine-grained sediments (fig. 21). This indicates that the iron which was deposited during lower Frasnian time was not carried into the area of deposition with the organic matter. The distribution of elementary iron appears differently if the concentrations are measured after the carbonates have been separated from the host-sediment samples. We did not evaluate the iron concentrations in samples from which the organic carbon had been separated, inasmuch as the concentrations in such samples are very low (table 68).

For carbonate-free sediments, the iron concentration increases as grain size decreases (from sandstones to clays), and the increase becomes a direct function of distance from the shore in the fine sediments (clays, limestones, and others). In short, an examination of the

[1] Translated from K geokhimii neftenosnykh otlozheny (inzhnefranskiye porody Vtorogo Baku): Akademiya Nauk SSSR, Trudy, Instituta Geologicheskikh Nauk, Geologicheskaya Seriya, no. 66, v. 155, p. 3-115. Part 1, including a complete abstract, and part 2 of this work appeared in the International Geology Review, v. 1, nos. 5 and 6, May and June 1959.

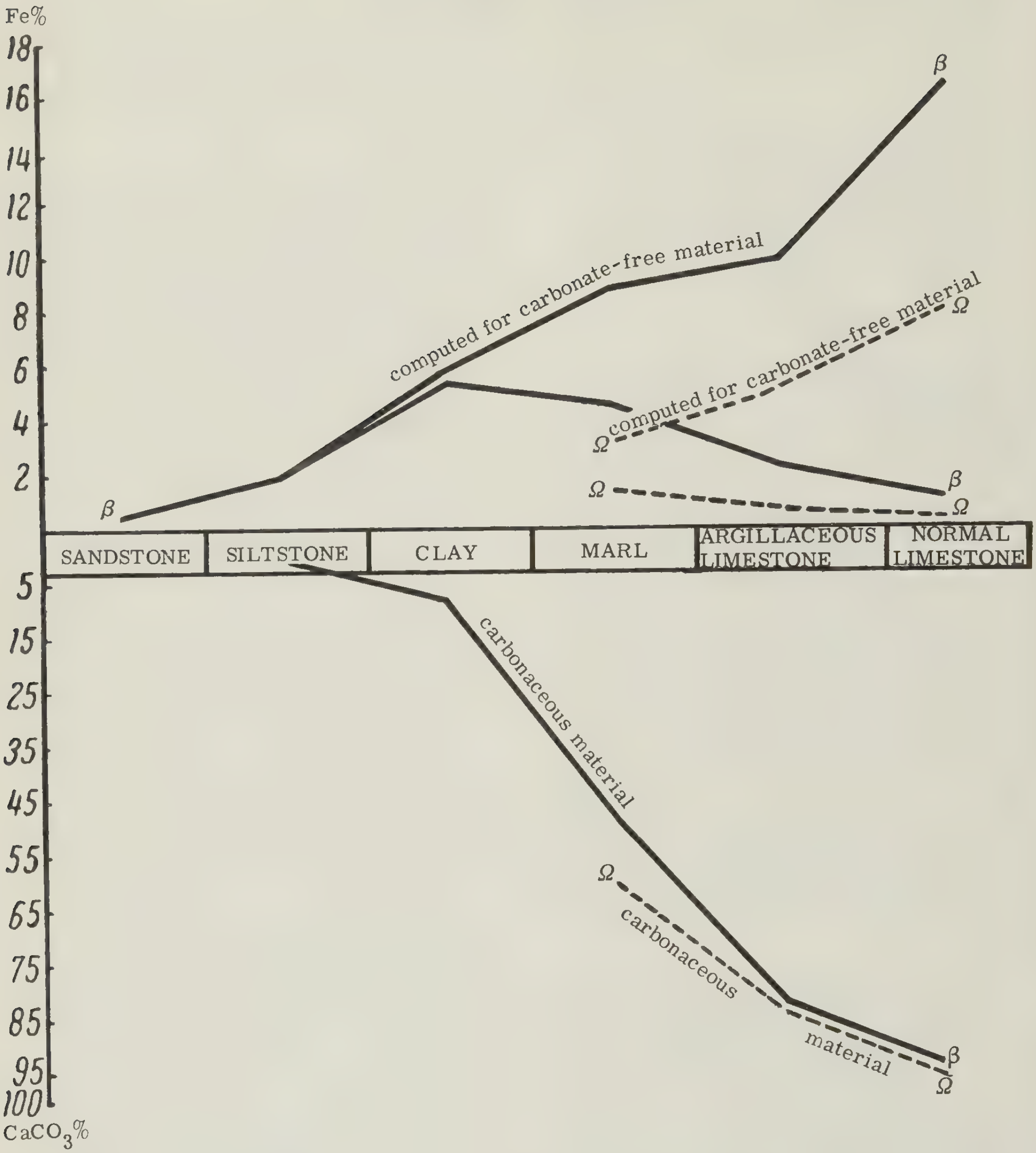

FIGURE 21. Distribution of iron in lower Frasnian sediments of the Volga-Urals province. β - Pashysky sediments; Ω - Domanik sediments

data on iron concentrations reveals that the largest amounts of iron are to be found in the central portions of basins of deposition and that only the large amounts of carbonates in these areas mask the very high iron/clastic ratios.

Total amounts of iron (as percentages of total sediments) in several Recent basins of deposition and the average concentrations for sedimentary rocks (according to Clarke) are shown in table 69; iron concentrations as percentages of carbonate-free materials are shown in table 70. The samples taken from the Sea of Japan and the bottom of Lake Baikal were extremely rich in authigenous SiO_2; consequently, the iron concentrations were computed as a percentage of material from which diagenetic silica had been eliminated. A comparison of these data and the data for the lower Frasnian of the Volga-Urals province reveals that the pattern of petrographic control of iron concentration is essentially the same in all cases; the expression of this control is clearer in some cases than in others. In addition, the percentage concentrations of iron in the lower Frasnian does not differ from the averages for all Recent

TABLE 67. Distribution of total iron in lower Frasnian sediments (as percentage of total rock)

Rock	Sandstone (7 samples)	Siltstone (17 samples)	Clay (19 samples)	Marl (12 samples)	Argillaceous limestone (14 samples)	Normal limestone and dolomite (3 samples)
Pashysky and sub-Domanik sediments with small average carbons concentrations	0.57	2.00	5.44	4.56	2.06	1.24
Limits of variation for iron concentrations in these rocks	(0.31-0.81)	(0.35-3.08)	(1.70-6.70)	(3.15-6.23)	(0.97-3.26)	(0.74-1.92)
Domanik sediments with large average carbon concentrations	-	-	-	(6 samples) 1.28	(3 samples) 0.79	(3 samples) 0.37
Limits of variation for iron concentrations in these rocks	-	-	-	(0.81-1.79)	(0.64-0.86)	(0.45-0.50)

TABLE 68. Distribution of total iron in carbonate-free lower Frasnian sediments (%)

Rock	Sandstone (7 samples)	Siltstone (17 samples)	Clay (19 samples)	Marl (12 samples)	Argillaceous limestone (14 samples)	Normal limestone and dolomite (3 samples)
Pashysky and sub-Domanik sediments with small concentrations of organic carbon	0.57	2.02	5.90	8.89	9.87	16.18*
Domanik sediments with large concentrations of organic carbon	-	-	-	3.17	4.65	7.94

* A sample with 30.67 percent iron concentration not included.

and ancient sediments. Specifically, the iron concentration values in the Pashysky and sub-Domanik sediments lie particularly close to the averages for all sedimentary rocks, in spite of the fact that the amounts of organic matter in these sediments are quite unique.

Although the Pashysky and sub-Domanik sediments include much oölitic hydrogoethite-chamoisite-siderite ore (Part 1), these ores are not very high grade. The presence of these iron ores in a basin of deposition which is indisputably marine and of rather large size does not seem to have affected the average iron concentrations beyond the limits of the ore beds. The ore bodies are small local deposits which formed in near-shore portions of the basin and which derived their iron from the load carried by surface- and ground-water discharged; this was demonstrated in the outline of lower Frasnian lithology which are presented in Part 1. The iron was precipitated quite rapidly near the shore; this is why no increase in concentration is to be observed elsewhere in the basin of deposition.

The influence of ore bodies upon iron concentrations beyond their lateral limits acquires clear-cut significance in light of our results. Negative results are only to be expected if all "ore bodies" are thought to contain only a negligible portion of the (respective) elements scattered through all sedimentary rocks. Uspensky and Radchenko [43] demonstrated that the total mass of humic hydrocarbons, calculated from carbon contents, is on the order of 10^{16} tons; the mass of humic hydrocarbons concentrated in coal beds is 10^{13} tons. The petroleums, on the other hand, contain something like 10^{10} tons of carbon, or 1/100,000 of the total organic carbon in sedimentary rocks. The mass of iron in sedimentary rocks according to Clarke, is on

TABLE 69. Distribution of iron in sediments of Recent basins of deposition (as percentage of total sediments)

Basin	Sands	Coarse silts	Fine silts	Pelites	Source
Barents Sea	0.92	1.51	2.69	3.5	Klenova [21]
Sea of Japan	2.45	3.29		3.36	
Lake Baikal	3.09	3.33	4.66	4.88	Data of the Department of Comparative Lithology, Inst. of Geological Science
Lake Balkhash	2.16	2.31	3.21	3.11	
Aral Sea	0.72	1.87		3.11	
Caspian Sea	0.22	0.41		1.85	Bruyevich, 1940; 10 percent extract
Black Sea	-	-	-	5.25	<u>Phaseolus</u> ooze with 22 percent $CaCO_3$
				4.74	Transitional ooze with 30.18 percent $CaCO_3$
				3.57	Calcareous ooze with 58 percent $CaCO_3$

TABLE 70. Total and adjusted iron concentrations in sediments of Recent basins of deposition (as percentages of sediment from which carbonates and authigenous silica have been eliminated)

Basin	Concentration	Sands	Silts	Argillaceous oozes	Marl oozes
Barents Sea	Total	0.92	2.10	3.50	-
	adjusted	1	2.3	3.8	-
Sea of Japan	Total	2.52	3.58	3.95	-
	adjusted	1	1.4	1.6	-
Lake Baikal	Total	3.09	4.85	5.47	-
	adjusted	1	1.57	1.77	-
Lake Balkhash	Total	2.23	3.84	-	7.25
	adjusted	1	1.72	-	3.25
Aral Sea	Total	0.75	2.35	-	4.13
	adjusted	1	3.1	-	5.5
Caspian Sea	Total	0.45	0.87	-	3.07
	adjusted	1	1.9	-	6.8
Black Sea	Total	-	-	7.5	15.4
	adjusted	-	-	-	-

the order 5×10^{16} tons; the world reserves of industrial-grade iron ore are 2.4×10^{12} tons according to 1937 figures which were computed from elementary iron concentrations (assuming potential reserves raise this value to 10×10^{12} tons). Even in this case, the iron ores will constitute only 1/5000 of all the iron in sedimentary rocks. The ratios between the ores and the dispersed iron minerals in the lower Frasnian are probably very similar, if we consider all of the Russian platform. These values demonstrate the strong local and limited nature of the process of ore deposition and the widespread deposition of iron over great areas of sea bottom. The figures also demonstrate the lack of effect of ore deposition upon the course of basinwide deposition.

This does not mean that the deposition of ore in the near-shore portions of very small basins will not affect the iron concentration in all portions of such a basin. The small amounts of iron which "escape" over the near-shore zone of ore deposition will, of course, increase the concentration in the entire lake or pond as they move into the open-water areas. No significant increase in overall concentration can be expected in a large marine basin like the lower Frasnian sea.

The pattern of iron distribution among the various types of sediments which constitute the Shchigry horizon is the same as the pattern of distribution for the various types of Recent sediments. Two fundamental factors govern the distribution of iron among Recent sediments: 1) iron is carried in suspension to seas and lakes by rivers and the iron component of the sedimentary load will therefore be dominated by fine particles; 2) the processes of chemical precipitation of dissolved iron. The gel aggregates created in the course of precipitation are

extremely fine (because of the negligible overall concentration of iron in water); therefore, these precipitates also are carried toward the central portion of the basin of deposition. Thus, an iron concentration which is high with respect to the clastic material is to be found in the central portions of a basin. The concentration of iron, calculated as a percentage of total sediments, will quite naturally decrease if the deposition of carbonates occurs simultaneously, for carbonates, by virtue of their fine texture, are also carried into the central portions of a basin of deposition; the average concentrations in these areas will be of the same order as in the near-shore areas. Such a distribution can be seen in Lake Balkhash, this perfectly regular and understandable distribution confirms the overall genetic scheme which we have outlined in this paper. The strong similarity between the distribution of iron concentrations in Recent sediments and in the lower Frasnian of the Volga-Urals province shows that the processes of deposition during the two intervals of time were similar and that the overall fundamentals (but not the details) of Recent sedimentation are applicable to the early Devonian.

This solution of the problem warrants an immediate comparison of the amounts of iron accumulated in Recent sediments and the amounts accumulated during the lower Frasnian. The amounts accumulated were different, and the differences can be analyzed by means of a somewhat different approach. The average concentration of iron in sands is expressed as unity and the concentrations in other types of sediments as multiples (or fractions) of the value for sand (table 71, fig. 22).

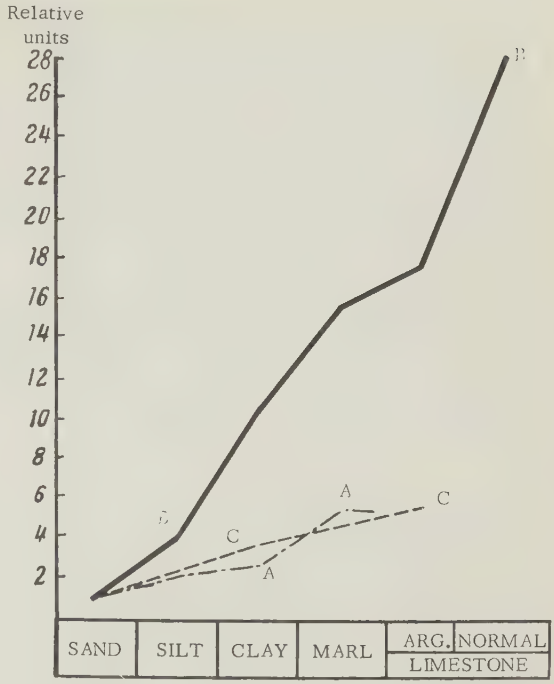

FIGURE 22. Distribution of iron in lower Frasnian and Recent sediments (in arbitrary units)

A. Average for Recent seas and lakes
B. Shchigry ores
C. Average for ancient seas

TABLE 71. Relative iron concentrations in sediments of various ages (%)

Age of sediments	Sand	Silt	Clay	Marl	Argillaceous limestone	Normal limestone
Recent	1	2.0	2.4	5.18	-	-
Pashysky and sub-Domanik	1	4.0	10.4	15.6	17.3	28.3

It is perfectly obvious (without additional explanations) that the difference between the concentrations in near-shore sandstones and pelitic clays in the Pashysky and sub-Domanik sediments is far greater than the difference between the corresponding facies in Recent sediments. The increase in iron concentrations for all Recent sediments from sands to silts (as percentages of carbonate-free material) is very small; the analogous increase for the sediments of Shchigry age is very sharp. Larger amounts of fine iron minerals were carried into the central portions of Shchigry basin and small amounts carried into Recent basins.

The great difference between the iron concentrations in the sandstones and siltstones of Shchigry age is understood quite readily when we consider the physical-chemical conditions in which these sediments were deposited. The climate over the low-level landmass which fed sediments into the Shchigry sea was moist, and the rocks of this landmass were subject to deep weathering; all of the iron minerals were decomposed to iron oxides chemically. The continents stand considerably higher at the present time; therefore, rapid mechanical erosion is a much more important process. The heavy minerals undergo almost no chemical decomposition, and very little iron oxide is produced in this manner. In Shchigry time, therefore, very little iron was transported into the sea as part of the silicate load carried by the rivers; the bulk of the iron was transported

as solutions (true and colloidal), as fine suspensions of $Fe_2O_3 \cdot H_2O$ gel, and as coagulated dissolved iron. The suspended masses of gel derived from the eroded weathered surface and created in the course of transportation were of negligible size (as they are in present-day streams). It is only natural that iron transported in this manner was deposited with the finest sediments, the clays and the marls. The sharp variation in iron concentration with sediment size in the Shchigry deposits is a direct consequence of the intense chemical weathering which occurred in the warm moist climate over the adjacent Devonian landmass. One is entitled to draw the general inference that the difference between the iron concentrations in near-shore and pelagic sediments varies directly with the intensity of the chemical weathering on the source land which feeds the basin of deposition.

Intense chemical weathering of a low-lying source land has another consequence: the ground waters are enriched with dissolved iron. The discharge of these waters in the near-shore areas of the open sea, as well as into lagoons and the waters of shielded archipelagos, involves an intensified deposition of oölitic and other iron deposits in near-shore waters. The development of such deposits in the near-shore of the Shchigry sea, where, as a rule, such sediments were laid down in very small amounts, would constitute a modification of the scheme of distribution of iron concentration in the Shchigry sea developed above. This modification would not be accidental; it would be quite within the framework of the scheme, inasmuch as it would be consequent upon the paleogeographic conditions which prevailed at the time.

A moist climate and intensive chemical weathering on the source land gave the major streams of the drainage network a load which entailed a sharp rise of the iron concentration in the pelagic sediments over the concentrations in the coarser near-shore sediments. The iron ores resulted from precipitation from ground water and small stream discharge into sheltered bays and lagoons from which the iron could not be carried into the open sea. The various forms of iron carried in surface runoff, together with the various (corresponding) environments of precipitation in the sea, created various distributions of iron concentrations in the sediments.

Analysis of the values in table 67 has revealed that the iron concentrations in Domanik marls and limestones are much lower than in the Pashysky and sub-Domanik marls and limestones. Apparently the difference in the concentrations is explained by the fact that the lithology of the areas from which the Domanik sediments were derived was not the same as the lithology of the area from which the Pashysky and sub-Domanik were derived. Specifically, this resulted in a decrease in the amount of iron in the Domanik sediments as a whole, while the distribution of iron-concentration magnitudes among the various lithofacies remained unchanged. In the Barents sea and Lakes Baikal and Balkhash, for example, the concentrations of iron in analogous lithofacies are very different; the distribution of concentrations among the various facies are virtually the same for all three basins. It is only natural to utilize this fact as a clue to the regularities and similarities in the distributions of concentrations in ancient sediments. We must repeat, however, that additional data are required for a final verdict on this matter and these data, as yet, are not available.

Comparison of the Geochemistries of Managanese, Phosphorus, and Iron in the Lower Frasnian of the Volga- Urals Province

Tables 72 and 73 show the distributions of manganese and phosphorus, as percentages by weight of total rock and carbonate-free material, for the lower Frasnian. An examination of the values in these tables shows that the distributions of manganese and phosphorus resemble that of iron in some respects and differ from the distribution of iron in others. The concentration of phosphorus, like the concentration of iron, increases from sandstones to clays, that is as average particle diameter decreases. Within pelitic sediments, the phosphorus concentration decreases as the carbonate concentration increases. The phosphorus concentration, like the iron concentration, increases steadily from the sandstones to the limestones if it is computed in percentages of carbonate-free material. The phosphorus concentration, unlike the iron concentration, is somewhat higher in the Domanik sediments, which are enriched with organic matter, than in the Pashysky and sub-Domanik sediments. One can see this immediately in the case of the marls (0. 17 percent in the Domanik and 0. 10 percent in the Pashysky and sub-Domanik). This increase is not apparent at first sight in the case of the clays and limestones but seems to occur in these sediments. The phosphorus concentration in the argillaceous limestones of Domanik age is similar to that of the sub-Domanik; contrary to lower values expected from analogy with iron and manganese. This lack of decrease in the phosphorus concentration is equivalent to an increase in concentration. The geochemistry of phosphorus is intimately related to the geochemistry of living matter, and an increase in organic material would, quite naturally, entail an increase in phosphorus.

The distribution of manganese has quite another set of characteristics. The most important of the features which distinguish this distribution from that of iron is the affinity of manganese for carbonate facies; consequently, a steady increase of the manganese concentration (expressed as a percentage of total sediments) is to be observed from the sandstones to clays, and then to the limestones. The values

TABLE 72. Distributions of manganese and phosphorus in lower Frasnian sedimentary rocks (as percentage of total rock)

Element	Sandstone	Siltstone	Clay	Marl	Argillaceous limestone	Normal limestone
A. Pashysky and sub-Domanik						
Manganese						
Average	0.010	0.022	0.052	0.065	0.073*	0.147
Range of variation	0-0.03	0-0.08	0.01-0.10	0.03-0.17	0.03-0.34	0.01-0.61
Phosphorus						
Average	0.016	0.032	0.072	0.105	0.065	0.035
Range of variation	0-0.03	0.01-0.08	0.05-0.12	0.09-0.26	0.03-0.28	0.01-0.07
B. Domanik						
Manganese						
Average	-	-	-	0.009	0.012	0.020
Range of variation	-	-	-	0.004-0.019	0.04-0.016	0-0.048
Phosphorus						
Average	-	-	-	0.17	0.06	-
Range of variation	-	-	-	0.11-0.27	0.024-0.123	-

* Samples with 3.4 percent manganese concentration excluded.

TABLE 73. Distribution of manganese and phosphorus in lower Frasnian sedimentary rocks (as percentages of carbonate-free sediments)

Element	Sandstone	Siltstone	Clay	Marl	Argillaceous limestone	Normal limestone
A. Pashysky and sub-Domanik						
Manganese	0.010 1	0.022 2.2	0.052 5.2	0.031 13.1	0.449 45	1.40 140
Phosphorus	0.016 1	0.035 2.3	0.079 5.0	0.204 12.8	0.313 19.5	0.509 31.8
B. Domanik						
Manganese	-	-	-	0.021	0.071	0.213
Phosphorus	-	-	-	0.43	0.39	-

for carbonate-free sediments indicate extremely high manganese concentrations in the pure limestones and argillaceous rocks. The range over which the concentrations vary is very wide. The sandstones and siltstones, for example, exhibit a number of zero values; many of the values in the carbonates, on the other hand, are much greater than the average. Thus, the average for several limestone specimens for Borovka well No. 2 is 0.24 percent, while argillaceous limestone and dolomite at Krym-Saray gave concentrations of 0.31 and 0.64 percent, respectively. Manganese seems to occur in limestones in the form of "aggregates" similar to the more familiar manganese concretions. It would appear, from the concentration in Domanik carbonates, that an increase in organic matter has no effect on the concentration of manganese in sediments, inasmuch as the manganese concentration in these rocks is lower than in the carbonates of sub-Domanik age.

A very interesting feature of the geochemistry of manganese and phosphorus--this feature distinguishes the geochemistry of these elements from that of iron -- is that the average concentration of each of these elements is assumed to be unity and the respective concentrations in other sediments are expressed as multiples of the concentration in sandstone (fig. 23). It is quite apparent in these plots that the increase in the concentrations of manganese and phosphorus in siltstones, clays, and marls follows a course only a little different from what followed by the increase in the concentration of iron; in argillaceous and pure limestones, however, the increase in manganese concentration (and to some degree the increase in phosphorus) is much sharper than the increase in the concentration of iron. A partition of the elements occurs, and the rates at which phosphorus and manganese concentrations increase with increasing distance from the shore increase.

Manganese- and phosphorus-concentration values for Recent sediments are given in tables 74, 75, and 76. The distribution patterns for the elements in Recent and lower Frasnian sediments are very similar; in both cases, the manganese and phosphorus concentrations

FIGURE 23. Concentrations of iron, manganese, and phosphorus in lower Frasnian sediments of the Volga-Urals province

TABLE 74. Granularometric control of manganese concentration in Recent sediments (as percentages of total dry sediments)

Sediment	Caspian Sea (A. S. Pakhomova)	Barents Sea (A. S. Pakhomova)
Sand	0.022	0.014
Silty sand	-	0.017
Sandy silt	0.052	0.027
Normal silt	0.152	0.031
Argillaceous silt	-	0.060

increase as the sediments become finer. The increase is much sharper in the lower Frasnian sediments. We can confirm this conclusion if we compare the values obtained when the concentrations of both elements in the sands of lower Frasnian and Recent age are taken as unity (table 77).

The differences among the concentrations in the various types of sediments of lower Frasnian age are much greater than the differences among the concentrations in corresponding Recent sediments; the increase in concentrations in the pelagic portions of the lower Frasnian sea is sharper than the corresponding increase for Recent environments. This is a complete repetition of the pattern which we observed in iron concentrations; it demonstrates that climate affects the geochemistry of all three elements in the same manner.

Elaborate studies of the distribution pattern for manganese and phosphorus concentrations in the lower Frasnian are probably not necessary, inasmuch as the pattern for these elements simply repeats the pattern for iron in the lower Frasnian as a whole. Even those features which distinguish the manganese and phosphorus pattern from the iron pattern (for example, the increase in the concentration of phosphorus in the organic-rich Domanik sediments) are entirely understandable and regular. The only features which require special investigation are the tendency of manganese to accumulate in the finest sediments and the intense variation in the local concentrations of this element. What is the origin of these characteristics of the geochemistry of manganese?

Elements with which we are concerned (Fe, Mn, P, V, Cr, Ni, Co, Cu) are in Recent sediments carried in solution and, mechanically, as constituents of other rocks [40]. Pelagic sediments will be enriched by any given element to the extent that the element is carried to the basin of deposition in solution; this is due, quite simply, to the fact that the chemical precipitates of the minerals which contain the elements with which we are concerned, without

TABLE 75. Granularometric control of manganese concentrations in Recent sediments

Sediment	Aral Sea	Lake Baikal	Sea of Japan	Black Sea	Black Sea sediments
Sand	0.026	0.051	0.04	-	
Coarse silt	0.037	0.052	0.156	0.055	Phaseolus ooze
Fine silt		0.086		0.066	Gray, deep-water clay
Argillaceous silt	0.07	0.101 (siliceous clay)	0.160	0.060	Transitional ooze
Argillaceous-calcareous silt (50 percent $CaCO_3$)	0.05		-	0.040	Calcareous ooze

TABLE 76. Granularometric control of manganese concentration in Recent sediments (as percentages of total sediments)

Sediment	Caspian Sea (M. L. Budyanskaya)	Aral Sea	Lake Baikal	Black Sea	Black Sea sediments
Sand	0.032	0.063	0.057	-	-
Silty sand	0.048	0.10	0.071	0.10	Phaseolus ooze
Sandy silt	0.063		0.077	0.11	Gray, deep-water clay
Normal silt	0.072	0.14 (clay)	0.086	0.10	Transitional ooze
Argillaceous silt	0.078	0.16 (argillaceous-calcareous silt)	0.140 (siliceous-argillaceous silt)	0.07	Calcareous ooze

TABLE 77. Comparison of manganese and phosphorus concentration in Recent and lower Frasnian sediments

Age	Sand	Silt*	Clay	Marl	Argillaceous limestone	Normal limestone
Manganese						
Recent	1	2.4	3.0	4.0	-	-
Lower Frasnian	1	2.2	5.2	13.0	45.0	140
Phosphorus						
Recent	1	1.6	2.15	4.8	-	-
Lower Frasnian	1	2.3	5.0	12.8	19.5	31.8

* This category includes the silty sands, sandy silts, and normal silts of Klenova's classification.

exception, are fine-grained and highly mobile. This allows ready transport toward the central portions of a basin of deposition, which explains the high concentrations of manganese in the fine argillaceous-calcareous lower Frasnian sediments. Transport in (true) solution is much more significant for manganese than for iron or phosphorus. The partition which occurred among the elements in this case was consequent upon the manner in which they were carried into the sea and not upon differences among their chemical behaviors in the sea itself. This explains the increased concentrations of manganese in the marl and limestone facies of the lower Frasnian; it does not explain the sharp variations in concentrations within each facies and the presence of nodular deposits of manganese in an environment in which iron nodules do not occur.

The explanation for the occurrence of nodular manganese lies in the high mobility of manganese in the zone of diagenesis and in its tendency to precipitate from solution after burial has begun. These properties of manganese give rise to zones of low concentration and zones in which local concentrations may increase to the value at which nodules make their appearance. The suggestion that manganese possesses a high mobility in the diagenetic environment has been advanced [40]. The concentrations of iron, manganese, and phosphorus in iron-manganese siderite, vivianite, and other nodules were compared with the concentrations of these elements in the sediments which included the nodules; the ratios of the iron, manganese, and phosphorus concentrations in nodules and host sediments were taken as measures of the mobility of these elements.

Many iron-manganese concretions are observed in the phaseoline oozes of the Black Sea; these concretions form about the shells of Modiola phaseolina. Samoilov and Titov established the chemical composition of these concretions (table 78). The concentrations in the

TABLE 78. Chemical compositions of iron-manganese concretions (%)

Ship taking samples	Fe	Mn	P
Meotidy	31.11	1.45	8.44
Meotidy	25.6	1.08	9.49
Albatross	31.10	1.08	9.45
Edinki	22.82	2.98	12.39

phaseolina ooze are as follows: iron, between 3.81 and 7.76 percent (average 5.25 percent); manganese, between 0.02 and 0.12 percent (average 0.055 percent); phosphorus, between 0.09 and 0.11 percent (average 0.10 percent).

If a unit magnitude is assigned to each of the average concentrations, the concentrations of the elements, with which we are concerned, in the concretions assumed the values shown in table 79. Concentration values for iron are the lowest, and the values for phosphorus and

TABLE 79. Iron, manganese, and phosphorus concentrations in iron-manganese concretions (%)

Ship taking samples	Fe	Mn	P
Meotidy	6.0	14.5	153
Meotidy	5.0	10.8	173
Albatross	6.0	10.8	152
Edinki	4.7	29.8	225
Average	[sic.] 4.3	16.5	176

manganese are much higher; the greatest values are for the manganese concentrations. The ascending order of concentrations, iron-phosphorus-manganese, is consequent upon an ascending order of mobility for the three elements. Similar results were obtained in the analysis of sediments taken from Lake Baikal, in which diagenetic minerals are especially abundant (table 80).

TABLE 80. Iron, manganese, and phosphorus concentration in Lake Baikal sediments

Sediment	Fe	Mn	P
Siliceous sediments	(4.35)	(0.10)	(0.14)
Diagenetic iron layers	1	1	1
Sample			
1	3.0	57.7	11.7
2	2.7	8.1	-
3	4.7	4.3	21.6
4	7.2	5.5	-
5	8.2	none	-
6	3.2	6.2	2.7
7	3.7	6.5	11.0
8	2.5	-	6.4
9	1.6	-	-
10	1.5	162	3
11	0.5	-	0.7
12	1.08	91.8	-
13	2.5	520.6	-
14	6.0	77.9	-
15	-	60.3	14.7
Average	3.5	83.5	9.0

Note: Values in parentheses designate concentrations in host sediments.

Note that the mobilities of iron, manganese, and phosphorus differ within the zone of diagenetic reduction (Lake Baikal), as well as in the zone of migration from the reducing to the oxidizing layer in the sediments (the case of the iron-manganese nodules in the Black Sea). The mobility of manganese is much greater than that of either iron or phosphorus. It will be precisely manganese, therefore, which will show the greatest range of concentrations in the lower Frasnian; the concentrations in some of the nodules included in these sediments are known to be as high as 0.64 percent.

The "Minor Elements" in the Lower Frasnian of the Volga-Urals Province

The mean concentrations of vanadium, chromium, nickel, cobalt, and copper in rocks of lower Frasnian age are shown in tables 81 and 82; these concentrations are in percentages of total and carbonate-free sediments. The concentrations of these elements are also plotted in figure 24.

The distribution of these elements in the natural sediments are strikingly regular and conform to the pattern which we have outlined for iron and phosphorus; the concentrations increase as one moves from the sandstones to the claystones, that is, the concentrations vary inversely with grain size. The concentrations decrease from claystones to limestones; they vary inversely with the amount of carbonate compounds. The argillitic limestones of Domanik age (very rich in organic matter) are characterized by especially high concentrations of nickel and vanadium. The copper concentration is slightly higher in these sediments, and the chromium and cobalt concentrations are not affected by the large amount of organic matter. The relationships become more complicated when concentrations are computed as percentages of carbonate-free material.

The minor elements fall into three groups: 1) nickel, cobalt, and chromium which are most highly concentrated in clays and marls and less highly concentrated from argillaceous to pure limestones; 2) vanadium, which is highest in clays and remains at this level, with very minor variations, in limestones; 3) copper which, like manganese and unlike the other minor elements, shows a steady and sharp increase in concentration from the sandstones to the limestones. The minor elements can be differentiated quite readily, but only in the central portions of the basin of deposition [28].

The manner in which the minor elements were transported into the sea, as was the case for iron, manganese, and phosphorus, may indicate the cause of differentiation. The bulk of the copper, like manganese, was transported in true solution. Considerably smaller amounts of vanadium, chromium, nickel, and especially cobalt were transported in true solutions. It is possible that these metals were transported in solution in negligible amounts; this would account for lack of increase in their concentrations computed as percentages of carbonate-free material in pelagic carbonates. It would seem that virtually all of the vanadium, chromium, nickel, and cobalt were brought into the basin of deposition (adsorbed) on particles of clay, inasmuch as these three elements seem to attain their highest concentrations among the pelitic sediments. This also explains why the vanadium concentration (computed as a percentage of the pelitic material) remains virtually constant in the facies, while the cobalt, chromium, and nickel concentrations decline somewhat in the carbonates; for the coarser pelitic materials do not reach the areas where the

TABLE 81. Distributions of Cu, Cr, Ni, Co, and V in lower Frasnian sedimentary rocks (in 10^{-4} percent of total rock)

Element and host rock	Sandstone	Siltstone	Clay	Marl	Argillaceous limestone	Normal limestone
Copper						
Pashysky and sub-Domanik	3	10	44	32	23	11
Domanik	-	-	-	73	24	14
Chromium						
Pashysky and sub-Domanik	none	10	34	17	12	none
Domanik	-	-	-	17	none (?)	none
Nickel						
Pashysky and sub-Domanik	1	12	42	36	14	3
Domanik	-	-	-	71	32	6
Cobalt						
Pashysky and sub-Domanik	none	5	8	4	none	none
Domanik	-	-	-	none	none	none
Vanadium						
Pashysky and sub-Domanik	none	33	104	72	23	12
Domanik	-	-	-	144	79	18

TABLE 82. Distributions of Cu, Cr, Ni, Co, and V in lower Frasnian sediments, computed for carbonate-free* material

Element	Concentration	Sandstone	Siltstone	Clay	Marl	Argillaceous limestone	Normal limestone
Copper	10^{-4}%	3	10	49	60	111	132
	relative	0.06	0.42	1	1.23	2.21	2.69
Chromium	10^{-4}%	none	10	37	33	33	none
	relative	0	0.27	1	0.89	0.89	0
Nickel	10^{-4}%	1	12	46	67	64	40
	relative	0.02	0.26	1	1.46	1.39	0.87
Cobalt	10^{-4}%	none	5	8	9	none	none
	relative	0	0.63	1	1.12	0	0
Vanadium	10^{-4}%	none	33	111	142	118	143
	relative	0	0.30	1	1.28	1.06	1.29

* The values in the table are based on an assigned unit magnitude for concentrations in clay.

carbonates are precipitated.

Unfortunately, we do not possess systematic data for the concentrations for these minor elements in Recent sediments; consequently, we do not know the extent to which the distribution which we find in lower Frasnian is repeated there. Zalmanzon [16] has published data on vanadium, chromium, nickel, cobalt, and copper concentrations in 29 samples of Paleozoic, Mesozoic, and Cenozoic sedimentary rocks from the Voronezh area and has computed mean concentration values (table 83). The ranges of variation are much greater than in the lower Frasnian of the Volga-Urals province, due, in part, to the quite random distribution of samples over the several types of sedimentary rock. The pattern which governs the distribution of concentrations is quite familiar. The concentration of each element increases from sandstones to clays (or marls) and decreases again as the amount of carbonate material begins to increase significantly. Such a pattern may be characteristic of vanadium, chromium, nickel, cobalt, and copper in all sedimentary rocks.

We pointed out above that the rock samples with which we are concerned were analyzed spectrographically as well as chemically. This procedure yielded an abundance of data on barium, strontium, lead, beryllium, and gallium concentrations and permitted a computation of certain mean concentration values. A scale of spectral intensity, which ranged from a value 1 for lines which may best be described as probably discernible to 10 for very bright lines, was adopted. The mean intensities were obtained by adding the scale values for a given line in all specimens tested spectrographically and dividing by the number of specimens. The concentration distribution curves, which were plotted from the spectrum intensity values for vanadium, chromium, nickel, cobalt, and copper, were in full agreement with the distribution curves plotted

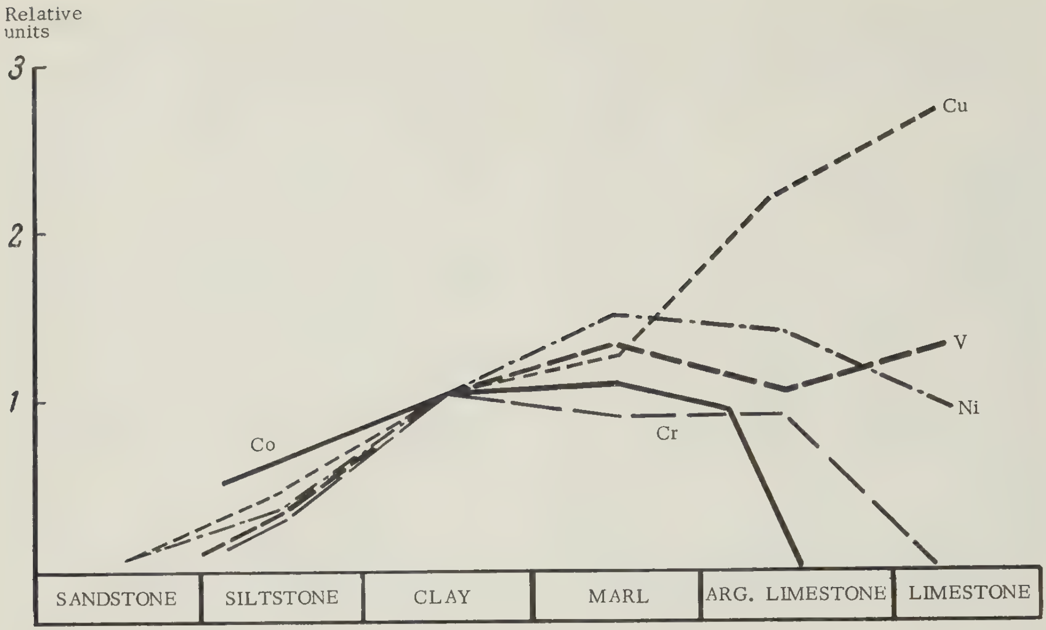

FIGURE 24. Distributions of minor elements in lower Frasnian sediments of the Volga-Urals province

TABLE 83. Distribution of minor elements in Paleozoic, Mesozoic, and Cenozoic rocks of the Voronezh massif (10^{-3} percent)
(after E.S. Zalmanzon [16])

Elements	Sand (2 samples)	Siltstone (9 samples)	Clay (2 samples)	Marl (2 samples)	Argillaceous limestone (2 samples)	Normal limestone (7 samples)
Vanadium	2.4	4.5	7.4	4.00	1.0	1.0
Chromium	1.45 (?)	1.0	4.9	1.7	1.10	0
Copper	1.25	4.0	4.0	2.9	4.6 (?)	2.5
Nickel	0.8	3.3	3.4	4.0	3.2	0.0
Cobalt	0.8	1.6 (?)	1.2	0.85	1.5 (?)	0.3
$CaCO_3$ (%)	0.24	5.0	7.5	49.6	82.5	93.46

from chemical analysis data [17]. There is reason to expect, therefore, that the concentration distributions obtained from spectrographic analysis will portray accurately the actual concentrations of the several elements in the rock.

The distribution pattern established for iron holds for all the elements except strontium. Its concentration increases from sandstones to clays and continues to increase from clays to carbonates. All elements show higher concentrations in carbonates than in clays when the concentrations are computed as percentages of carbonate-free material. The clay-to-carbonate

TABLE 84. Concentrations of Ba, Sr, Pb, Be, and Ga in lower Frasnian sediments from spectrographic determinations
(in arbitrary units for total sediment)

Elements	Sandstone	Siltstone	Clay	Marl	Argillaceous limestone	Normal limestone
Barium	1.3	2.9	3.6	3.1	1.2	0.3
Strontium	0.4	1.6	2.5	3.1	3.5	3.2
Lead	none	0.2	0.3	0.3	0.3	none (?)
Beryllium	0.4	0.8	1.8	1.5	0.5	0.8
Gallium	none	0.2	1.8	1.6	0.8	none

increase in strontium is much sharper than the of any other element. All five minor elements were carried into the lower Frasnian sea in solution and were precipitated chemically. The amount of dissolved strontium, must have been exceptionally high. The strontium was precipitated, apparently, by a process which involved a capture of its ions by crystalline $CaCO_3$; for it is a familiar fact that Recent marine waters are drastically undersaturated by strontium. The undersaturation was probably even more acute in the Devonian seas.

Overall Distribution of the Elements in the Lower Frasnian Sediments of the Volga-Urals Province

The striking similarities among the distributions of a large number of chemical elements in sedimentary rocks constitute a basis for a set of propositions which, apparently, are valid for all sedimentary rocks, not merely for the lower Frasnian of the Volga-Urals province. The propositions are as follows:

1. Each chemical element is distributed among the lithofacies of a basin of sedimentation according to a characteristic pattern; this pattern may be termed the geochemical profile of the element.

2. A comparison of the geochemical profiles for all of the elements included in the lower Frasnian sediments of the Volga-Urals province reveals that the profiles are very similar for the (horizontal) lithofacies sequence sandstone-siltstone-clay, and very dissimilar for the sequence clay-marl-limestone. The concentrations (computed as percentages of clastic material) of all the elements increase uniformly over the first sequence; the increases for some elements are greater than the increases for others. Fundamental differences among the profiles are to be observed over the second sequence. Some elements (iron, manganese, phosphorus, copper, strontium) show an increase in concentration if the last is computed as a percentage of carbonate-free material. The concentrations of other elements (vanadium, for example) remain virtually constant percentages of clastic material. Still other elements (chromium, nickel, cobalt, and others) show declines in concentration. The differences among the geochemical profiles, therefore, are least in the sandstone and siltstone (near-shore) facies and greatest in the clay-limestone (pelagic) facies. If the assumption that the concentrations in the clays have unit magnitude is taken as the basis of a profile plot, the curves will spread fanwise towards the central portions of the basin of deposition. This distribution pattern has nothing in common with the pattern postulated by Pustovalov on theoretical grounds.

3. The fundamental factors which control the distribution of each element among the lithofacies of a basin of deposition are: a) the ratio between the dissolved and suspended portions of the elements; b) the distribution of the elements among the granularometric components of the suspended load. The concentration of a given element in the sediments laid down in the central portions of a basin will vary directly with the proportion of the element that is brought into the basin in the dissolved state. On the other hand, the sharpness of the drop in the concentration of a given element from clastic to carbonate facies increases directly with the proportion of coarse material in the suspended load. The distribution of concentrations among the granularometric components of the suspended load will depend upon the proportions in which the element is partitioned between capture by crystal lattices and adsorption by clay particles.

4. An increase in the intensity of chemical weathering on the source land entails an increase in the amount of mineral matter that is decomposed in a manner such that chemical elements are liberated. This entails a drop in the concentrations of these elements in the coarse near-shore clastics and an increase in the fine pelagic sediments. The difference between the concentrations in near-shore and pelagic sediments increases; this can be seen in the iron, manganese, and phosphorus concentrations in the Recent and lower Frasnian sediments of the Volga-Urals province.

Low source-land relief and a moist climate (and the intensified chemical weathering resulting from moist climatic conditions) favor the appearance of oölitic iron ore depositions in the near-shore areas when these circumstances are combined with the presence of lagoons and other embayments and the discharge of ground water. Thus, the same set of factors, moist climate and intense chemical weathering, give rise to two depositional processes which at first glance seem to be mutually exclusive, but which actually are simply consequent upon differences among local depositional environments.

5. The deposition of carbonate sediments has a largely "passive" effect upon the concentration of elements. It lowers the concentrations to the extent that these sediments accumulate. There are instances in which the deposition of carbonates affects the concentration of some elements positively. Strontium, for example, seems to be deposited chemically and biochemically with calcium carbonate. The deposition of other elements probably involves similar processes.

6. Organic matter apparently has a great influence on the precipitation of certain elements. The concentrations of these elements tend to increase in sediments which are rich in organic carbon. This is observed in the cases of vanadium, nickel, molybdenum, and (to some extent) phosphorus.

TABLE 85. Elementary compositions

Well	Sample number	Sampling depth(m)	Number of specimens	Insoluble residue	'A' hydrocarbons (computed)			
					C	H	N+S+O	C/H
Tukmakly No.9	1559-1563	1502-1507	Post-Domanik (6)	33.82	75.50	9.77	14.73	7.71
Borovka No. 2	1761-77-1818	1623-1815	Domanik (1)	30.50	80.37	9.31	10.32	8.63
Sernovodsk No.3	19, 16, 14, 10	1980-2002	Domanik (3)	25.98	80.18	9.41	10.41	8.52
Tukmakly No. 9	composite	1526-1530	Domanik (7)	28.44	81.34	9.64	9.02	8.44
Baltayevo No. 2	composite	1743-1758	Domanik (9)	19.37	80.28	10.93	8.79	7.35
Borovka No. 2	1816	1834-1861	Sub-Domanik clay and marl (2)	47.55	68.85	8.94	22.21	7.70
Sernovodsk No.3	1933, 37, 40	2047-2062	Sub-Domanik (4)	32.84	70.84	8.65	20.51	8.19
Sernovodsk No.3	1976-77	2073-2080	Sub-Domanik (5)	34.05	67.88	7.91	24.21	8.58
Tukmakly No.9	composite	1530-1535	Sub-Domanik (8)	56.26	63.10	7.58	29.32	8.32
Syzran No.190	726-727	1512-1517	Siltstone	99.80	70.00	6.80	23.20	10.29
Berezovka No.8	908-12-13	1819.3-1823	Siltstone	97.33	70.63	7.12	22.25	9.91
Berezovka No.8	980-985	1872-1888	Siltstone	94.88	64.47	7.64	27.89	8.43
Berezovka No.8	1024-1028	1910-1917	Siltstone	94.96	71.29	8.54	20.17	8.35
Sernovodsk No.3	2022-2030	2126-2132	Siltstone	62.15	-	-	-	-
Borovka No.3	2093-2100	1961-1966	Siltstone	66.41	-	-	-	-
Borovka No.3	2130-2136	2018-2022	Siltstone	94.75	-	-	..	-
Tukmakly No.9	2686-2690	1692-1657	Siltstone	72.50	-	-	-	-
Tukmakly No.9	2649-2654	1731-1740	Siltstone	93.80	69.21	7.92	22.87	8.75
Tukmakly No.9	2672-2674	1783-1787	Siltstone	68.14	72.80	7.61	19.59	9.56
Krym-Saray No.3	3745	1766-1774	Siltstone	57.72	76.77	8.17	15.06	9.40
Krym-Saray No.3	3781	1810-1813	Siltstone	92.76	-	-		-
Baltayevo No.2	4553	1814-1819	Siltstone	94.77	63.74	6.46	29.80	9.87
Krym-Saray No.3	3764-66-67	1782-1801	Argillite	89.63	80.50	8.51	10.99	9.46
Baltayevo No.2	4564	1845-1850	Marl	30.87	80.83	8.75	10.42	9.21
Borovka No.3	2157-2162	2047-2054	Limestone	2.62	-	-	-	-

TABLE 85. Elementary compositions

Well	Acetone solution					Chloroform solution				
	C	H	N	O+S	C/H	C	H	N	O+S	C/H
Tukmakly No.9	67.54	8.39	2.23	21.84	8.05	76.17	8.90	2.10	12.83	8.56
Borovka No.2	74.35	8.99	1.83	14.83	8.27	80.80	8.29	1.96	8.95	9.70
Sernovodsk No.3	65.16	8.25	3.12	23.47	7.89	81.06	7.76	1.15	10.03	10.44
Tukmakly No.9	77.84	11.07	0.26	10.83	6.97	82.96	7.46	1.60	7.98	11.12
Baltayevo No.2	83.23	10.03	0.17	6.57	6.39	79.39	8.01	2.45	10.15	9.91
Borovka No.2	64.41	8.50	2.88	24.21	7.58	-	-	-	-	-
Sernovodsk No.3	58.64	6.75	3.76	30.85	8.66	78.66	7.80	13.54		10.08
Sernovodsk No.3	68.93	7.37	2.25	21.45	9.35	73.53	7.95	2.31	16.21	9.25
Tukmakly No.9	58.41	7.13	3.80	30.66	8.19	-	-	-	-	-
Syzran No.190	68.96	6.28	2.62	22.14	11.00	72.31	6.81	20.88		10.62
Berezovka No.8	67.88	6.55	1.92	23.65	10.36	-	-	-	-	-
Berezovka No.8	61.48	6.80	2.62	29.10	9.06	-	-	-	-	-
Berezovka No.8	61.81	8.65	29.54		7.14	-	-	-	-	-
Sernovodsk No.3	59.28	7.39	33.33		8.02	-	-	-	-	-
Borovka No. 3	64.70	6.85	3.69	24.76	9.44	-	-	-	-	-
Borovka No. 3	61.55	6.82	31.63		9.0	-	-	-	-	-
Tukmakly No. 9	59.10	5.98	3.03	31.89	9.88	70.34	8.05	21.61		8.74
Tukmakly No. 9	64.88	7.78	3.42	23.92	8.34	73.38	7.23	19.39		10.15
Tukmakly No. 9	65.85	6.46	1.42	26.30	10.19	77.28	7.24	15.48		10.67
Krym-Saray No. 3	74.40	7.60	1.82	16.18	9.79	74.25	7.98	17.77		9.30
Krym-Saray No. 3	52.73	8.19	3.83	35.25	6.43	-	-	-	-	-
Baltayevo No. 2	61.76	6.15	0.56	31.53	10.04	-	-	-	-	-
Krym-Saray No. 3	76.10	8.04	3.80	12.06	9.46	75.23	8.31	3.51	12.95	9.05
Baltayevo No. 2	75.96	8.59	3.55	11.90	8.84	79.41	8.46	2.71	9.42	9.39
Borovka No. 3	64.43	8.84	26.73		7.30	-	-	-	-	-

of hydrocarbon fractions (%)

Oils, extracted by low temperature					Resins in benzene solution					Asphaltene				
C	H	N	O+S	C/H	C	H	N	O+S	C/H	C	H	N	O+S	C/H
87.01	12.50	0.0	0.49	6.96	81.50	9.50	9.00		8.6	-	-	-	-	-
86.80	11.85	0.025	1.35	7.32	81.02	9.56	9.42		8.5	75.53	7.86	2.13	14.48	10.26
87.26	12.50	0.0	0.24	6.98	81.20	9.44	9.36		8.6	78.13	7.70	2.76	11.41	10.14
86.34	11.84	0.0	1.82	7.29	84.35	9.46	1.77	4.42	8.9	79.01	7.22	1.70	12.07	10.94
86.53	12.28	0.0	1.19	7.07	83.50	9.14	1.34	6.02	9.1	77.53	7.32	2.86	12.29	10.59
87.90	12.10	0.0	0.0	7.26	83.41	10.6	1.15	4.84	7.7	-	-	-	-	-
87.00	12.31	0.07	0.62	7.07	84.42	10.65	0.72	4.21	7.9	-	-	-	-	-
87.80	12.13	0.07	0.0	7.24	84.55	10.47	0.85	4.13	8.1	-	-	-	-	-
87.55	11.33	0.11	1.01	7.72	82.27	10.28	7.45		8.0	-	-	-	-	-
81.32	11.91	6.77		6.82	79.54	8.69	0.85	10.92	9.2	-	-	-	-	-
87.40	12.62	0.04		6.96	-	-	-	-	-	-	-	-	-	-
86.51	12.78	0.71		6.77	-	-	-	-	-	-	-	-	-	-
86.90	11.67	1.43		7.44	75.82	7.26	0.71	16.21	10.4	-	-	-	-	-
-	-	-		-	71.36	7.46	21.18		9.6	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
87.75	12.22	trace	0.03	7.18	-	-	-	-	-	72.79	7.99	19.22		9.10
-	-	-	-	-	72.36	8.85	1.13	17.66	8.7	-	-	-	-	-
88.0	10.82	0.0	1.18	8.13	74.72	7.46	0.45	17.37	10.10	-	-	-	-	-
87.62	11.96	0.42		7.32	80.52	9.44	0.80	9.24	8.5	-	-	-	-	-
86.61	12.48	0.91		6.94	85.45	10.39	0.79	3.37	8.3	84.64	8.72	6.64		9.72
84.86	11.02	0.0	4.12	7.78	-	-	-	-	-	75.69	8.00	16.31		9.44
87.06	11.73	0.0	1.21	7.42	75.24	6.71	1.0	17.05	11.2	-	-	-	-	-
87.63	11.45	0.0	0.92	7.65	86.81	9.45	0.78	2.96	8.3	81.31	7.65	1.36	9.68	10.63
88.99	10.83	0.18	0.0	8.22	82.40	8.78	1.28	7.54	9.38	75.04	7.95	3.04	13.97	9.44
	-	-	-	-	-	-	-	-	-	-	-	-	-	-

of hydrocarbon fractions (%) (Concluded)

'C' hydrocarbons in chloroform solution					'C' hydrocarbons in acetone solution				
C	H	N	O+S	C/H	C	H	N	O+S	C/H
-	-	-	-	-	57.91	7.08	0.19	34.82	8.2
75.85	7.92	16.23		9.6	62.99	7.25	1.98	27.78	8.7
78.37	8.32	1.38	11.93	9.4	-	-	1.36	-	-
77.29	7.96	1.29	13.46	9.7	-	-	-	-	-
78.13	8.15	1.20	12.52	9.6	-	-	0.79	-	-
-	-	-	-	-	57.61	7.43	0.15	34.81	7.8
-	-	-	-	-	-	-	0.04	-	-
-	-	-	-	-	59.16	6.77	0.45	33.62	8.7
-	-	-	-	-	62.76	7.98	1.30	27.96	7.87
-	-	-	-	-	58.85	6.72	0.50	33.93	8.8
-	-	-	-	-	-	-	1.17	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	61.71	7.10	31.19		8.69
-	-	-	-	-	-	-	0.70	-	-
68.40	8.50	23.10		8.1	-	-	0.65	-	-
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	54.18	5.90	39.92		9.18
-	-	-	-	-	62.76	7.98	1.22	28.04	7.9
-	-	-	-	-	60.50	7.36	32.14		8.22
-	-	-	-	-	61.41	7.02	0.67	30.90	8.74
-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	54.38	5.89	0.81	38.92	9.2
-	-	-	-	-	60.24	6.76	0.51	32.45	8.90
65.69	7.39	26.92		8.8	60.26	6.69	0.93	32.12	9.0
-	-	-	-	-	61.25	7.17	31.58		7.58

TABLE 86. Composition of organic

Well	Sample number	Sampling depth (m)	Lithologic source	Insoluble residue	Organic C	Hydrocarbons (% of total rock)	
						'A'	'C'
Tukmakly No. 9	1559-1563	1502-1507	Post-Domanik (6)	33. 82	0. 68	0. 252	0. 251
Borovka No. 2	1761-1770-1880	1623-1815	Domanik (1)	30. 50	3. 78	1. 435	0. 970
Sernovodsk No. 3	1916, 1410, 118	1980-2002	Domanik (3)	25. 98	3. 32	1. 379	0. 226
Tukmakly No. 9	Composite	1526-1930	Domanik (7)	28. 44	4. 02	2. 004	0. 807
Baltayevo No. 2	Assembled	1743-1758	Domanik (9)	19. 37	5. 28	2. 350	0. 251
Borovka No. 2	1816, 20	1834-1861	Sub-Domanik clay and marl (2)	47. 55	0. 93	0. 153	0. 490
Sernovodsk No. 3	1933, 37, 40	2047-2062	Sub-Domanik (4)	32. 84	0. 88	0. 148	0. 366
Sernovodsk No. 3	1976, 77	2073-2080	Sub-Domanik (5)	34. 05	1. 49	0. 236	0. 188
Tukmakly No. 9	Laminated	1530-1535	Sub-Domanik (8)	56. 26	0. 55	0. 143	0. 071
Syzran No. 190	726-727	1512-17	Siltstone	89. 90	1. 08	0. 313	0. 091
Berezovka No. 8	908-12-13	1819. 3-1823	Siltstone	97. 33	0. 42	0. 033	0. 022
Berezovka No. 8	908-85	1872. 9-1888. 6	Siltstone	94. 88	0. 55	0. 088	0. 071
Berezovka No. 8	1024-1027	1910-1917. 7	Siltstone	94. 96	1. 20	0. 105	0. 027
Sernovodsk No. 3	2022-2030	2126-2132	Siltstone	62. 15	0. 42	0. 087	0. 042
Borovka No. 3	2093-2106	1961-1966	Siltstone	66. 41	0. 56	0. 114	0. 114
Borovka No. 3	2130-2136	2018-2022	Siltstone	94. 75	0. 32	0. 040	0. 034
Tukmakly No. 9	2686-2690	1692-1657	Siltstone	72. 50	0. 89	0. 129	0. 048
Tukmakly No. 9	2649-2654	1731. 4-1740	Siltstone	93. 80	0. 94	0. 195	0. 083
Tukmakly No. 9	2672-2674	1783. 4-1787. 2	Siltstone	68. 14	0. 87	0. 084	0. 049
Krym-Saray No. 3	3745	1766. 5-1774. 7	Siltstone	57. 72	1. 26	0. 093	0. 070
Krym-Saray No. 3	3781	1810. 3-1813. 9	Siltstone	92. 76	0. 70	0. 067	0. 020
Krym-Saray No. 3	3764, 66, 67	1782-1801	Clay	88. 63	8. 38	0. 665	0. 609
Baltayevo No. 2	4553	1814-1819	Siltstone	94. 77	4. 17	1. 038	0. 168
Baltayevo No. 2	4564	1845-1850	Marl	30. 87	6. 04	0. 973	0. 531
Borovka No. 3	2157-2162	2047-2054	Limestone	2. 62	0. 11	0. 066	0. 045

matter by fractions

Humic acid	Composition by fractions of organic matter (%)						Composition of 'A' hydrocarbons by fraction (%)			Extracts in various solvents (% of total)			
	'A' hydrocarbons	'C' hydrocarbons: Chloroform solution	'C' hydrocarbons: Acetone solution	Total hydrocarbons	Humic acid	Residual organic matter	Oil	Resin	Asphaltene	Petroleum ether	Benzene	Acetone	Chloroform
trace	28. 00	1. 30	19. 10	48. 40	trace	51. 60	28. 92	41. 83	29. 25	41. 66	9. 12	47. 61	1. 61
trace	30. 51	2. 21	15. 29	48. 01	trace	51. 99	27. 05	33. 75	39. 20	48. 78	23. 58	15. 26	12. 38
trace	33. 30	2. 57	2. 33	38. 20	trace	61. 80	26. 29	29. 55	44. 65	42. 21	34. 37	11. 74	11. 68
trace	40. 50	3. 26	11. 05	54. 85	trace	45. 15	31. 02	28. 72	40. 26	42. 99	18. 36	18. 16	20. 49
trace	35. 73	1. 94	1. 47	39. 14	trace	60. 86	28. 69	24. 64	46. 47	48. 42	21. 70	20. 21	9. 67
trace	11. 30	2. 10	29. 67	43. 07	trace	56. 93	8. 41	26. 94	64. 65	16. 99	11. 76	68. 62	2. 63
trace	11. 91	2. 29	22. 84	37. 04	trace	62. 56	17. 05	26. 64	56. 31	35. 80	13. 51	45. 94	4. 75
trace	10. 75	2. 34	5. 16	18. 25	trace	81. 75	16. 50	23. 56	59. 94	35. 59	11. 86	40. 25	12. 30
trace	16. 41	2. 36	5. 84	24. 59	trace	75. 41	5. 66	21. 99	72. 35	14. 68	8. 39	73. 42	3. 51
0. 013	20. 28	2. 84	3. 11	26. 23	0. 90	72. 87	2. 29	24. 42	73. 29	-	8. 31	90. 41	1. 28
0. 0063	5. 55	2. 78	2. 01	10. 34	1. 12	88. 54	3. 84	28. 86	69. 50	-	63. 63	32. 99	3. 38
0. 0091	10. 32	2. 91	5. 21	18. 44	1. 24	80. 32	3. 74	30. 69	65. 57	-	12. 5	84. 09	3. 41
0. 014	6. 24	0. 47	0. 92	7. 63	0. 88	91. 49	15. 60	24. 46	59. 94	13. 33	50. 47	34. 28	1. 92
trace	14. 50	2. 32	3. 92	20. 74	trace	79. 26	9. 92	50. 00	38. 89	6. 90	13. 79	75. 86	3. 45
trace	14. 25	2. 55	9. 86	26. 66	trace	73. 34	13. 55	48. 54	37. 33	11. 40	15. 79	70. 17	2. 64
0. 0005	8. 75	3. 54	5. 88	18. 17	0. 11	81. 72	15. 35	14. 16	70. 49	-	62. 50	32. 50	5. 00
trace	10. 14	1. 20	1. 88	13. 22	trace	86. 78	9. 02	37. 68	53. 30	-	31. 01	62. 12	6. 87
trace	14. 36	2. 56	3. 08	20. 00	trace	80. 00	6. 39	27. 25	66. 36	-	18. 46	80. 00	1. 54
trace	7. 03	1. 34	2. 16	10. 53	trace	89. 47	13. 75	46. 72	39. 53	-	45. 24	46. 43	8. 33
0. 026	5. 67	1. 29	2. 19	9. 15	1. 55	89. 30	1. 97	29. 80	68. 23	-	22. 58	70. 97	6. 45
0. 0068	6. 98	1. 11	0. 7	8. 79	0. 72	90. 49	13. 21	28. 54	58. 65	10. 45	20. 90	67. 16	1. 49
0. 005	6. 39	1. 07	3. 33	10. 79	0. 37	88. 84	19. 11	41. 72	39. 00	18. 92	28. 98	46. 25	5. 85
0. 036	15. 86	1. 29	1. 11	18. 26	0. 47	81. 27	6. 51	82. 05	11. 44	-	6. 65	92. 00	1. 35
0. 002	13. 02	1. 65	4. 94	19. 61	trace	80. 39	23. 43	45. 57	31. 00	22. 21	34. 63	35. 46	7. 70
trace	-	-	-	-	-	-	12. 50	48. 18	37. 92	10. 61	18. 18	66. 66	4. 55

Many of the features of the distribution of the elements in the lower Frasnian are to be observed in other ancient and Recent deposits. The The suggestion that the inferences drawn from these distributions had a broader significance is warranted. A fuller confirmation of this presupposes additional studies of ancient marine and lacustrine sediments. Such studies constitute the program to which our group shall address itself.

REFERENCES

1. Arkhangelsky, A. D., USLOVIYA OBRAZOVANIYA NEFTI NA SEVERNOM KAVKAZE [CONDITIONS OF THE EVOLUTION OF PETROLEUM IN THE NORTHERN CAUCASUS]: Moscow-Leningrad, Sov. Neft. Prom., Izvestiya, 1927.

2. Babko, A. K., PRIMENENIYE TVERDYKH VOSSTANOVITELEY [SOLID REDUCING AGENTS]: Zavodskaya Laboratoria, 1937, no. 6.

3. Baturin, V. P., O PROISKHOZHDENII NEFTI [THE ORIGIN OF PETROLEUM]: Moskovskoye Obshchestvo Ispytateley Prirody, Trudy, 1945, no. 20.

4. Bruyevich, S. V., and Ye. T. Vinogradova, OSADKOOBRAZOVANIYE V KASPYSKOM MORE [SEDIMENTATION IN THE CASPIAN SEA]: Inst. Okeanol., Trudy, 1949, no. 3.

5. Budyanskaya, M. L., MIGRATSII FOSFORA V DONNYKH OTLOZHENIYAKH KASPYSKOGO MORA [MIGRATION OF PHOSPHORUS IN THE BOTTOM SEDIMENTS IN THE CASPIAN SEA]: Gos. Okeanol. Inst., Trudy, v. 5, no. 17, 1948.

6. Veber, V. V., OBSHCHIYE REZULTATY ISSLEDOVANIYA. V Kn.: K POZNANIYU SOVREMENNYKH ANALOGOV NEFTENOSNYKH FATSY [GENERAL RESULTS OF INVESTIGATIONS. In: RECENT ANALOGUES OF RESERVOIR FORMATIONS]: Moscow-Leningrad, 1950.

7. __________, TIP OSADKOV I NAKOPLENIYE V NIKH ORGANICHESKOGO VESHCHESTVA. V Kn.: K POZNANIYU SOVREMENNYKH ANALOGOV NEFTENOSNYKH FATSY [TYPE OF SEDIMENT AND ACCUMULATION AND ITS ORGANIC MATTER. In: RECENT ANALOGUES OF RESERVOIR FORMATIONS]: Moscow-Leningrad, 1950.

8. Vinogradov, A. P., KOLORIMETRICHESKOYE OPREDELENIYE VANADIYA S FOSFORO-VOLFRAMOVOY KISLOTOY [COLORIMETRIC DETERMINATION OF VANADIUM IN PHOSPHOTUNGSTIC ACID]: Akademiya Nauk SSSR, Doklady, Seriya A, 1913, no. 10.

9. Voytova, Ye. V., K VOPROSU OPREDELENIYA BITUMOV V PODMOSKOVNOM BUROM UGLE [THE PROBLEM OF HYDROCARBON DETERMINATIONS IN MOSCOW BASIN BROWN COAL]: Khimiya Tverdogo Topliva, v. 7, no. 4, 1936.

10. Gorskaya, A. I., ISSLEDOVANIYE ORGANICHESKOGO VESHCHESTVA SOVREMENNYKY OSADKOV. V Kn.: K POZNANIYU SOVREMENNYKH ANALOGOV NEFTENOSNYKH FATSY [AN INVESTIGATION OF ORGANIC MATTER IN RECENT SEDIMENTS. In: RECENT ANALOGUES OF RESERVOIR FORMATIONS]: Moscow-Leningrad, 1950.

11. Gubkin, I. M., UCHENIYE O NEFTI [A STUDY OF PETROLEUM]: Moscow-Leningrad, 1932.

12. Gulyayeva, L. A., OPREDELENIYE MALYKH KOLICHESTV NIKELYA V OSADOCHNYKH PORODAKH [DETERMINATION OF MINOR AMOUNTS OF NICKEL IN SEDIMENTARY ROCKS]: Zhurnal Prikladnoy Khimiya, v. 18, nos. 11-12, 1945.

13. Gulyayeva, L. A., and Ye. S. Itkina., OPREDELENIYE MALYKH KOLICHESTV MEDI V OSADOCHNYKH PORODAKH [DETERMINATION OF MINOR AMOUNTS OF COPPER IN SEDIMENTARY ROCKS]: Zhurnal Prikladnoy Khimiya, v. 17, nos. 4-5, 1944.

14. Dobryansky, A. F., GORYUCHIYE SLANTSY SSSR [BITUMINOUS SHALES IN THE U. S. S. R.]: Moscow-Leningrad, 1947.

15. __________, GEOKHIMIYA NEFTI [GEOCHEMISTRY OF PETROLEUM]: Moscow-Leningrad, 1948.

16. Zalmanzon, E. S., MALYYE ELEMENTY V RAZREZAKH VORONEZHSKOY OBLASTI. V Kn.: VOPROSY LITOLOGII STRATIGRAFII SSSR [TRACE ELEMENTS IN THE VORONEZHSK CROSS SECTION. In: QUESTIONS ON LITHOLOGY AND STRATIGRAPHY IN THE U. S. S. R.]: Akademiya Nauk SSSR, Izvestiya Pamyati Akad. A. D. Arkhangelskogo, Moscow, 1951.

17. Zalmanzon, E. S., and N. V. Lizunov, O SRAVNIMOSTI DANNYKH KHIMICHESKOGO I SPEKTRALNOGO ANALIZA PRI LITOLOGICHESKIKH ISSLEDOVANIYAKH [A COMPARISON OF CHEMICAL AND SPECTROGRAPHIC DATA IN LITHOLOGICAL INVESTIGATIONS]: Akademiya Nauk SSSR, Doklady, v. 86, no. 6, 1952.

18. Zalmanzon, E. S., and Ye. S. Shishova, ZHELEZO, MARGANETS, FOSFOR I MALYYE ELEMENTY V NIZHNEFRANSKIKH OTLOZHENIYAKH VTOROGO BAKU [IRON, MANGANESE, PHOSPHORUS AND TRACE ELEMENTS IN THE LOWER FRASNIAN SEDIMENTS OF THE VOLGA-URALS]: Akademiya Nauk SSSR, Doklady, v. 85, no. 4, 1952.

19. Zvenigorodskaya, V. M., KOLORIMETRICHESKOYE OPREDELENIYE KOBALTA V ZHELEZONIKELEVYKH RUDAKH PIROFOSFATNO-RODANOBYM METODOM [A PYROPHOSPHATE-THIOCYANOGEN COLORIMETRIC DETERMINATION OF COBALT IN IRON-NICKEL ORES]: Zvodskaya Laboratorya, 1938, no. 2.

20. Klenova, M. V., INSTRUKTSIYA PO MEKHANICHESKOMU ANALIZU [PROCEDURES IN MECHANICAL ANALYSIS]: Gos. Okeanogr. Inst., Instruktsii, 1933, no. 8.

21. ________, GEOLOGIYA MORYA [MARINE GEOLOGY]: Moscow, 1948.

22. Kondratyeva, M. G., and I. I. Yengurazov, DEVONSKIYE OTLOZHENIYA SARATOVSKOGO POVOLZHYA [DEVONIAN SEDIMENTS OF THE SARATOV SECTION OF THE VOLGA VALLEY]: Akademiya Nauk SSSR, Izvestiya, Seriya Geologiya, 1915, no. 2.

23. Mikryukov, M. F., and K. R. Timergazin, NOVYYE DANNYYE PO STRATIGRAFII I LITOLOGII TERRIGENNYKH OTLOZHENY BAVMINSKO-TUYMAZINSKOGO RAYONA [NEW DATA ON THE STRATIGRAPHY AND LITHOLOGY OF TERRIGENOUS SEDIMENTS IN THE BAVMINSK-TUYMAZY AREA]: Neftyanoye Khozyaystvo, 1948, no. 9.

24. Miropolsky, L. M., L. F. Solontsov, and N. M. Kovyazin, OB OOLITOVYKH RUDAKH V INZHNEFRANSKIKH OTLOZHENIYAKH BASHKIRII I TATARII [A CONTRIBUTION ON OÖLITIC ORES IN THE LOWER FRASNIAN OF BASHKIRIA AND TATARIA]: Akademiya Nauk SSSR, Kazansky Filial, Izvestiya, Seriya Geologicheskikh Nauk, 1950, no. 1.

25. Miropolsky, L. M., K. R. Timergazin, L. F. Solontsov, N. M. Kovyazin, and [?. ?.] Kiligina, O DEVONSKIKH OOLITOVYKH ZHELEZNYKH RUDAKH V ZAPADNOY BASHKIRII I VOSTOCHNOY TATARII [DEVONIAN OÖLITIC IRON ORES IN WESTERN BASHKIRIA AND EASTERN TATARIA]: Akademiya Nauk SSSR, Doklady, v. 66, no. 1, 1949.

26. Pakhomova, A. S., MARGANETS V MORSKIKH OSADKAKH [MANGANESE IN MARINE SEDIMENTS]: Gos. Okeanogr. Inst., Trudy, v. 5, no. 17, 1948.

27. Pistrak, R. M., FATSII DEVONSKIKH I KAMENNOUGOLNYKH OTLOZHENY RUSSKOY PLATFORMY I SVYAZIKH SO STRUKTUROY [LAYERED SEQUENCE IN THE DEVONIAN AND CARBONIFEROUS FACIES OF THE RUSSIAN PLATFORM]: Akademiya Nauk SSSR, Institut Geologicheskikh Nauk, Trudy, Geologicheskaya Seriya, v. 101, no. 39, 1950.

28. Pustovalov, L. V., PETROGRAFIYA OSADOCHNYKH POROD [PETROGRAPHY OF SEDIMENTARY ROCKS]: Moscow, 1940.

29. Putsillo, V. G., ISSLEDOVANIYE BITUMOV KIZELOVSKOGO RAYONA [INVESTIGATION OF THE HYDROCARBONS OF THE KIZEL DISTRICT]: Akademiya Nauk SSSR, Izvestiya, I. M. Gubkina M., 1951.

30. Radchenko, O. A., SOVREMENNYYE PREDSTAVLENIYA O GENEZISE NEFTI I PROTSESSAKH PREOBRAZOVANIYA I RASRUSHENIYA [CURRENT VIEWS ON THE ORIGIN, EVOLUTION, AND METAMORPHISM OF PETROLEUM]: Akademiya Nauk SSSR, Izvestiya, I. M. Gubkina, M., 1951.

31. Radchenko, O. A., I. P. Karpova, and A. S. Chernysheva, OPYT GEOKHIMICHESKOGO ISSLEDOVANIYA VYVETRELYKH GORYUCHIKH ISKOPAYEMYKH VYSOKOY STEPENI METAMORFIZATSII NA MATERIALAKH YUZHNOY FERGANY [INVESTIGATIONS OF THE GEOCHEMISTRY OF INTENSELY WEATHERED HIGH-GRADE METAMORPHIC ROCKS IN THE SOUTHERN FERGANA BASIN]: Vses. Neft. Nauchno-Issoled. Geol.-Rasv. Inst., Trudy, v. 57, 1951.

32. Radchenko, O. A., and O. Ya. Fedorova, GEOKHIMICHESKIYE MATERIALY PO VOPROSU O NEFTENOSNOSTI KIZELOVSKOGO RAYONA [GEOCHEMICAL DATA ON PETROLEUM RESERVES IN THE KIZEL DISTRICT]: Vses. Neft. Nauchno-Issoled. Geol.-Rasv. Inst., Trudy, v. 28, 1949.

33. Rodionova, K. F., O PREVRASHCHENII ORGANICHESKOGO VESHCHESTVA POD VLIYANIYEM MIKROBOV MORSKIKH ILOV I NEFTI V SVYAZI S VOPROSOM O NEFTEOBRAZOVANII [THE CONVERSION OF ORGANIC MATTER IN BOTTOM SEDIMENTS INTO PETROLEUM BY BACTERIA AND THE PROBLEM OF THE ORIGIN OF PETROLEUM]: Akademiya

Nauk SSSR, Izvestiya, Pamyati Akad. I. M. Gubkina M., 1951.

34. Romm, I. I., GEOKHIMICHESKAYA KHARAKTERISTIKA SOVREMENNYKH OTLOZHENY TAMANSKOGO POLUOSTROVA [GEOCHEMISTRY OF RECENT SEDIMENTS OF THE TAMAN PENINSULA]: In: K Poznaniyu Sovremennykh Analogov Neftenosnykh Fatsy, Moscow-Leningrad, 1950.

35. Savich, V. G., FIZIKO-KHIMICHESKAYA KHARAKTERISTIKA VODOYEMOV I OSADKOV TAMANSKOGO POLUOSTROVA [THE PHYSICAL CHEMISTRY OF WATERS AND SEDIMENTS IN THE TAMAN PENINSULA REGION]: In: K Poznaniyu Sovremennykh Analogov Neftenosnykh Fatsy, Moscow-Leningrad, 1950.

36. Samoylov, Ya. V., and A. G. Titov, ZHELEZO-MARGANTSEVYYE KONKRETSII SO DNA CHERNOGO, BALTYSKOGO I BARENTSOVA MOREY [IRON-MANGANESE CONCRETIONS OF THE BOTTOMS OF THE BLACK, BALTIC, AND BARENTS SEAS]: Akademiya Nauk SSSR, Geol. i Min. Muzeya, v. 3, 1922.

37. Sanin, P. I., V. G. Putsillo, and S. P. Uspensky, BITUMY I BITUMINOZNYYE PORODY KEMBRYSKIKH OTLOZHENY [HYDROCARBONS AND HYDROCARBON-BEARING ROCKS OF CAMBRIAN AGE]: Akademiya Nauk SSSR, Nefti Institut, Trudy, v. 1, no. 2, 1950.

38. Strakhov, N. M., DOMANIKOVAYA FATSIYA YUZHNOGO URALA [DOMANIK FACIES IN THE SOUTHERN URALS]: Akademiya Nauk SSSR, Geologichesky Institut, Trudy, Geologicheskaya Seriya, v. 16, no. 6, 1939.

39. __________, RASPREDELENIYE ZHELEZA V OSADKAKH OZERNYKH I MORSKIKH VODOYEMOV I FAKTORY, YEGO OPREDELYAYUSHCHIYE [FACTORS CONTROLLING THE DISTRIBUTION OF IRON IN MARINE AND LACUSTRINE ENVIRONMENTS]: Akademiya Nauk SSSR, Izvestiya, Seriya Geologicheskaya, 1948, no. 4.

40. Strakhov, N. M., N. G. Brodskaya, L. M. Kiyazeva, A. N. Razzhivina, M. A. Rateyev, D. G. Sapozhnikov, and Ye. S. Shishova, PROTSESSY OBRAZOVANIYA OSADKOV V SOVREMENNYKH VODOYEMAKH [SEDIMENTATION PROCESSES IN RECENT BASINS OF DEPOSITION]: Akademiya Nauk SSSR, Izvestiya, Moscow, 1954.

41. Teodorovich, G. I. SIDERITOVAYA GEOKHIMICHESKAYA FATSIYA MOREY I VOOBSHCHE SOLENYKH VOD KAK NEFTEPROIZVODYASHCHAYA [SIDERITE FACIES IN SEAS AND OTHER SALINE WATERS AS PETROLEUM SOURCE BEDS]: Akademiya Nauk SSSR, Doklady, v. 69, no. 2, 1949.

42. Uspensky, V. A., and A. I. Gorskaya, ISSLEDOVANIYA PO KHIMII PRIRODNYKH ASFALTOV [A STUDY OF THE CHEMISTRY OF ASPHALTS]: Vses. Neft. Geol.-Rasv. Inst., Trudy, Novaya Seriya, v. 17, 1941.

43. Uspensky V. A., and O. A. Radchenko, K VOPROSU GENEZISA TIPOV NEFTEY [A CONTRIBUTION ON THE EVOLUTION OF VARIOUS TYPES OF PETROLEUM]: Vses. Neft. Geol.-Rasv. Inst., Trudy, Novaya Seriya, v. 19, 1947.

44. Uspensky V. A., and A. S. Chernysheva, VESHCHESTVENNYY SOSTAV ORGANICHESKOGO MATERIALA IZ NIZHNESILURYSKIKH IZVESTNYAKOV V RAYONE G. CHUDOVO [COMPOSITION OF THE ORGANIC MATTER IN THE LOWER SILURIAN LIMESTONES OF THE CHUDOVO DISTRICT]: Vses. Neft. Geol.-Rasv. Inst., Trudy, Novaya Seriya, v. 57, 1951.

45. Uspensky, V. A., A. S. Chernysheva, and Yu. A. Mandrykina, O RASSEYANNOY FORME NAKHOZHDENIYA UGLEVODORODOV V RAZLICHNYKH OSADOCHNYKH PORODAKH [DISPERSED HYDROCARBONS IN SEDIMENTARY ROCKS]: Akademiya Nauk SSSR, Izvestiya, Seriya Geologicheskaya, 1949, no. 5.

46. Uspensky, V. A., A. P. Shishkova, and N. A. Antonovskaya, ISSLEDOVANIYE SERY BITUMINOZNYKH OBRAZOVANY, SVYAZANNYKH OPREDELENNYMI GENETICHESKIMI OTNOSHENIYAMI [SOME GENETIC CHARACTERISTICS OF HYDROCARBONS]: Vses. Neft. Nauchno-Issled. Geol.-Razv. Inst., v. 28, 1949.

47. Frost, A. V., and L. K. Osnitskaya, K VOPROSU O PROISKHOZHDENII NEFTI [THE PROBLEM OF THE ORIGIN OF PETROLEUM]: Akademiya Nauk SSSR, Izvestiya, Pamyati Akad. I. M. Gubkina, 1951.

48. Shakhkeldian, A. V., KOLORIMETRICHESKY METOD OPREDELENIYA MEDI [THE COLORIMETRIC DETERMINATION OF COPPER CONCENTRATIONS]: Zhurnal Prikladnoy Khimiya, 1929, no. 4.

49. Clarke, F., THE DATA OF GEOCHEMISTRY, 1929.

50. Krumbein, W., and R. Garrels, ORIGIN AND CLASSIFICATION OF CHEMICAL SEDIMENTS IN TERMS OF pH AND OXIDATION-REDUCTION POTENTIAL: Journal of Geology, 1952, no. 1.

51. Sandell, E. B., DETERMINATION OF CHROMIUM, VANADIUM, AND MOLYBDENUM IN SILICATE ROCKS: Indiana Chemical Engineering, v. 8, no. 5, 1936.

ON CERTAIN STRATIGRAPHIC FUNDAMENTALS[1]

by

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• translated by P. F. Moore •

ABSTRACT

Stratigraphic fundamentals, rules, terminology, and nomenclature require extensive clarification for universal usability. At present, little agreement on stratigraphic definitions and terminology has been reached. Three systems of terminology must be distinguished: 1) prostratigraphy, or preliminary stratigraphy without chronology; 2) stratigraphy, which is intimately concerned with time; and 3) chronology, or absolute time measurement without regard to rock units and their correlation. The Hedberg system of lithostratigraphy, biostratigraphy, and chronostratigraphy is discussed. A glossary of the terminology of stratigraphic and chronologic units is established. -- G. E. Denegar.

INTRODUCTION

The International Geological Congresses took as one of their many tasks the duty of ruling on, and clarifying, the fundamentals, rules, terminology, and nomenclature of stratigraphy. With this object, a commission for the unification of stratigraphic nomenclature and classification was set up at the first Congress in Paris in 1878, which laid its findings before the second Congress in Bologna in 1881. In Stockholm in 1910, the commission for the lexicon of stratigraphy was established which up to this time has produced no activity of any sort.

In the year 1952 at the Congress in Algiers, things were reorganized. A commission on stratigraphy was established which had two subcommissions: a) for the lexicon of stratigraphy and b) for stratigraphic terminology. The eminence of its president (R. C. Moore) and his secretaries led one to expect a prosperous development. In any case, responsible and important tasks were given to the Commission, which can be interpreted in the sense of a standing watch and appeal court. It seems to me that the function of the second subsection is of special importance as it deals with the fundamental questions and decisions which specially F. R. S. Henson [7] and W. J. Arkell [1] have put forward as the object of an international commission.

With regard to stratigraphic definitions and terminology, we are still very far from general agreement. H. D. Hedberg, Secrectary of the Subcommission for Stratigraphic Terminology, laid before the Congress in Algiers a memorandum entitled, "Procedure and Terminology in Stratigraphic Classification" and transmitted the manuscript to the members of the Commission, although only a short résumé appeared in print [5]. Hedberg's thoughtful and prudent perspective outline established an excellent basis for discussion and criticism which was invited by the author.

As the German member of the Commission I allowed myself, since this opportunity had been afforded, to publish a few general thoughts on the subject. I did this in the full consciousness that my point of view was apparently very far from that expressed in the report and therefore might seem to be very one-sided. That is due naturally in part to entirely personal differences. On the other hand I have gained the impression that more or less collectively, the stratigraphic thought and methods in North America and in the Old World, at least in a part of Europe, have considerably diverged from one another in many matters.

The United States has its own active commission for stratigraphic nomenclature. We do not have any particular body which makes it its business to clarify the fundamentals of stratigraphy from the point of view of our perhaps rather differently established conditions and premises. Now and then we find the plethora of organizations, commissions, committees, congresses, and meetings a heavy burden, so we shall not here suggest calling into being a new organization of this type. However, perhaps I may invite those colleagues who are interested in the question, to join in as lively a discussion as possible, because I would like to know, for the work of the forthcoming International Geological Congresses, what are the dominant opinions and wishes of our geologists. Any well-founded opinion is welcome. To give this stimulus is one aim of the following pages. My other aim is to bring to our honored colleague, Fritz Dahlgrün, a special present on his 60th birthday and therewith, to associate my very best wishes for him and his family.

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[1]Translated from Über einige stratigraphische grundbegriffe: Roemeriana, v. 1, Dahlgrün-Festschrift, p. 23-38, 1954.

[2]Geology-Paleontology Institute of the University of Tübingen, Germany.

STRATIGRAPHY, CHRONOLOGY, AND PROSTRATIGRAPHY

Stratigraphy is that geological discipline which has as its object that study of the historical sequence of those strata available to us. The historical point of view is thus the specific ordering principle. Stratigraphy is therefore not simply the description of strata; if that were the case it would be identical with petrography and would be merely an aspect of general geology. Nor is it a part of paleontology, as this has to deal with fossils and not with strata.

We find that in stratigraphy, as in all historical matters, the time concept plays an essential role and is inextricably bound up with it. The accomplishment of stratigraphy depends on criteria which are known to us as contemporaneity, time equivalence, and sequence. The time scale which is inseparably connected therewith is provided by geological chronology which is itself not stratigraphy because it is completely separated from the strata with their concrete individuality and is created through the abstract of a true time framework. The marks of this time scale, for that part of the geological column which G. H. Chadwick [2] has called the Phanerozoic, are taken from the phylogenetic development of organisms.

Chadwick, in the above-mentioned work, divided geological time into the Cryptozoic and the Phanerozoic. This was unknown to me at the time [16] when I proposed the division into a Petrogäikum and a Biogäikum. The former comprises that period in which we have no known fossils preserved and for whose stratigraphic study we depend on petrographic content and methods, while in the Biogäikum the animal and floral fossils form the basis of the historical description. Both concepts indicate about the same thing. Only the first is clearly based on time whereas the second deals with concrete earth history.

We arrive first of all at a clear division between stratigraphy and chronology each of which has its own distinct logical structure. Chronology is nonmaterial, abstract; it depends on a universally valid time scale, without anything to say on the subject of historical geological content. On the other hand, stratigraphy has to do with material geological data; it concerns itself with concrete strata and occurrences in these same chronological periods.

From this it follows that the word stratigraphy may not be used when it does not have an inherent time connotation. In a territory which is completely unexplored geologically we may observe a sequence of sandstones, shales, and limestones, whose geological age is unknown to us. We would in such a case describe the sequence of strata and perhaps also we would label their particular members with preliminary local names, but this is not stratigraphy. On the basis of the principle of superposition one can say with considerable probability that the beds follow each other in the observed manner but there is no certainty to be had on the matter without the criteria of age, that is to say of time; the strata under discussion could possibly be overturned.

Local observations and descriptions of strata merely build up the raw material for stratigraphy. They are the forerunners of stratigraphy. In order to become a genuine stratigraphy the local observations must be methodically linked together. The methodical key to this lies in the introduction of the time concept. Petrostratigraphy or lithostratigraphy is thus no true stratigraphy but the raw material which one can call "Prostratigraphy."

HEDBERG'S SYSTEM

Lithostratigraphy

Departing from this simple scheme which assigns a quite restricted meaning to stratigraphy, Hedberg, and with him other North American colleagues, have built up quite a complicated system of correlation principles and methods for stratigraphy. This system gives rise to a further complicated heirarchy of concepts which, in my opinion, rather confuse than clarify the issue.

According to Hedberg, the work of the stratigrapher begins at a given outcrop with the description of the thickness and petrographic constitution of the beds. Then "zones" are established at this outcrop on the basis of rock character, and then neighboring sections are correlated by means of these "zones." This preliminary work is called "rock stratigraphic (lithostratigraphic) classification," and is an arrangement into purely lithologically or lithogenetically determined units. The basic unit of this scheme is the "formation" which is given a local name and comprises a set of beds with similar petrographic constitution. Several neighboring formations may be united into a group. On the other hand a single formation may be further subdivided into members, lentils, and tongues.

A sandstone formation, for example, might be subdivided into thin-bedded or thick-bedded, into fine-grained or coarse-grained "members." When the rock character changes in a horizontal direction, which may happen in an outcrop quite near the type locality, then those formations which were previously established need, and indeed should, no longer be carried; new formation names are introduced in their place. Thus overlaps can occur. The fine-grained Roseville member of the Redville formation may go over anywhere into a coarse-grained sandstone and thus take on at locality B the petrographic character of the coarse-grained Carmineville mem-

ber at locality A.

These lithostratigraphic units are, it is said, founded on objective physical criteria. They are, by definition, completely independent of the time factor and their bounding surfaces do not have the character of time surfaces. They can comprise extremely varied types of deposits and it is absolutely permissible to unite in one formation the beds of two successive geological systems such as, for example, a Cretaceous and Tertiary sandstone when they form an apparently continuous deposit and have uniform petrographic character. Formations should, however, be separated at larger unconformities. For instance, a Miocene limestone which had been deposited on the erosional surface of a Cretaceous limestone is to be placed, if possible, in another formation, even when the petrographic constitution of both limestones is exactly the same. But that would presume that there are criteria which would allow one to make this age distinction. In contrast to the definition which has been given for rock units the time factor is here brought into the picture in spite of the fact that it is against the general pronouncements of North American workers [22, 23]. So age determinations on the basis of fossils for the separation of grouping of rock units still have to be used.

Already at this stage there is divergence of opinion on many points:

1. The meaning of "formation" in English-speaking writings and also Hedberg's zonal concept are quite different from our usage. I shall have a few words to say on this subject later.

2. "Formations" play a very important part in American publications (According to R. C. Moore [10] there are about 10, 000 stratigraphic names employed in North America of which by far the greatest number fall into the category of "formations. ") but we hardly use them, if at all, in that sense of the word.

Indeed, we also speak of Nehdener slates but we do not mean by this simply a slaty rock. We mean a slate of a particular restricted age carrying within it the goniatite <u>Cheiloceras</u> as an indicator of its age. We would consider it quite inadmissible either in stratigraphic classification or for purposes of map illustration to group these Nehdener slates with the underlying Büdesheimer slates into a "formation" although petrographically they belong to the same pyrite-rich slate facies. The Büdesheimer is clearly separated in age from the Nehdener slate through the appearance of <u>Manticoceras</u> and we grant to this time criterion a superior place to the petrographic. The Middle-Upper Devonian boundary in Europe is spanned by a very homogeneous reef-limestone facies. However, we make a separation within this petrographically uniform rock mass and we call the Middle Devonian part the Schwelmer and the Upper Devonian part the Iberger limestone.

The local names which we use to distinguish the members are in many cases old names and originally had a purely petrographic significance, which our North American colleagues wish their formations to retain. This former local petrographic significance has, however, now been completely set aside; the designations have been recast into time-defined units of regional and supraregional validity. We give the name Iberger limestone then not only to the Upper Devonian reef limestone from Iberg near Grundt in the Harz mountains but also to the reef limestone of similar age in the Rhine Gebirge and the Frankenwald of the Sudeten. Only through the introduction of the time factor have we raised the originally local designations to the rank of stratigraphic terms.

And such true stratigraphic units will also be the divisions used on the geological maps, at least that is what we are striving for; and these will not only display simple lithology as Wheeler and Mallory [22] demand. For practical aims, raw-material maps and so forth, the latter method may have its points but not for a scientific geologic map. It is self evident that the units which we use in cartography are not abstract time units but material rock strata which have, however, been made stratigraphically significant by taking the time factor into account. It cannot be denied that mistakes may thus arise. But when we dread all possibility of error then all scientific work may well come to a standstill.

3. The classification of purely petrographically determined "formations" can, in the light of the above introduction be hardly considered as scientific, theoretically based, stratigraphy. When sequences of variously named formations are set up, measured by minor petrographic variations from place to place without the attempt and - through the elimination of the time unit - without any possibility of linking them together in an exact manner, then it can only have a preliminary significance. Through the unconnected naming of formations the separate members are only self-defined and thus there is naturally no increase of knowledge.

Certainly, in lightly explored territories, or in poorly fossiliferous terranes, there are occasions where, for the time being, no other course is open, and for purely practical reasons one has to get by with these methods. But then, there is no stratigraphy. A method which specially names each individual outcrop and renounces the restoration of their connections and equivalences must be designated protoscience. It is rather similar to the first step in biological morphology which knows nothing of the ordering principle of homology and thus labels the various homologous organs in each form with different names. Obviously in micropaleontology we can,

for purely practical reasons, use figures and symbols and thus renounce all taxonomic organization and all biological connections, but one cannot call that scientific paleontology. I would by analogy, describe Hedberg's usage of the rock stratigraphic classification as Prostratigraphy.

In the Cryptozoic for the present we can only employ a Prostratigraphy of this kind, which cannot be compared to true stratigraphy in detail and reliability. No fossils worth naming are to be expected here but a broader framework of absolute age determination may, we hope, be established in order to put the raw Prostratigraphy on the time basis of true stratigraphy.

Biostratigraphy

A further principle of stratigraphic classifications is, according to Hedberg, "biostratigraphic classification." Here the fossils are introduced but merely as material components of the rocks in the same sense as he was also considering the mineral components. They serve - if I have correctly interpreted the meaning of the author - only as distinguishing characters of the respective strata, as indicators of their mode of origin and of the environment of sedimentation, but not of their age classification.

The main unit of this classification category is the fauni- or florizone defined as a bed or a group of beds which is characterized by a particular assemblage of organisms. One of the forms is taken as index fossil and gives its name to the unit even in those cases where it is not confined to this unit or is not found in a particular part of it (Nummulites zone, Cyathocrinus bed). Faunizones can be subdivided into sub-faunizones and these further into zonules. On the other hand the faunizones can be grouped into either super- or megazones.

The distinguishing faunas change or disappear both in the horizontal and in the vertial directions by change of facies; they come back with a return of the same facies conditions. All that takes place quite regardless of any time boundaries. Fossils are also given a place of importance as ecological but not as time indicators. Faunal zones are only applicable to those strata which carry their respective faunas. They are therefore not valid for other kinds of sediments where the faunal assemblage is lacking owing to facies differences.

Hedberg has also endowed the biozone with a completely separate biostratigraphic significance. It embraces the totality of beds in which a particular species occurs. In the vertical section the biozones are only a substitute for teilzones; thus the time span which comprises the sum of all the teilzones composes the time duration of the biozone. In this manner the biozones serve for the correlation of strata (In an earlier publication [15, 16], I have followed K. Andrée and R. Staesche in attacking the misuse of the word correlation which is particularly widespread in Anglo-Saxon speech, and also unfortunately widespread in German writing. I must here remind you that correlation means, also in English, correspondence between objects and concepts that stand in opposite relation to one another. In logic it means the mutual interrelationship of postulated or presumed objects, especially circumstances. Correlation therefore means something that is, but which we cannot do. The taking over of the meaning for the equating of strata is therefore not possible; the geologist can compare, arrange, classify, coordinate, and equate but not correlate.) and are the main paleontological grounds for the classification of the rocks in the geologic time scale. I have the impression that we are dealing here with two completely different things which are being confused with one another. Biostratigraphy, in Hedberg's sense, which however hardly covers the usual meaning of this word, covers in part what I [16] have called ecostratigraphy. By that I understand the stratigraphic occurrence of local or regional faunal or floral assemblages which are valuable for ecology or for hypothetical mechanical or stratinomic considerations. They consist of components which, in a quite arbitrary manner, are separated from their true life range. In such cases, however, the true range of species is not established by recurrent facies change and in fact cannot be known. We are dealing here with a stratigraphic method which is clearly only applicable to a limited regional extent and which guarantees no valid enlightenment for stratigraphy. Ecostratigraphy is therefore to be classed with the prostratigraphic procedures. But the biozone in its proper sense implies something quite different; namely, a clear chronological indicator system of supraregional significance.

Chronostratigraphy

Hedberg calls all the above-mentioned procedures and units "objective" because they are based on physical criteria. He contrasts with them the time or chronostratigraphic classification as a subjective method. But once again two quite separate things are being brought together: 1) time stratigraphic units, material units which comprise all the rocks which were deposited in a given geological time interval - this time interval is defined by establishing a type section; and 2) geological time units which are nonmaterial and not stratigraphic time intervals which are necessary for the deposition of the rocks in the aforementioned time stratigraphic units.

Hedberg's time stratigraphic classification signifies then what we designate as true genuine stratigraphy, whereas the other classification system is, as Hedberg rightly points out, not stratigraphic but chronologic. The distinction between stratigraphy and chronology which we consider essential also cuts clean through these categories of Hedberg's principles of classification.

It does not seem to me to be correct to contrast the objective and subjective units which, for example, was also made a feature of the publication by Wheeler and Mallory [22] and by Woodring [23]. Certainly petrostratigraphy, which is the forerunner of a genuine clarified stratigraphy, is not a clearly objective method. We are not dealing with dolomite, sandstone, and so forth as objective data but with rock material which we, perhaps wrongly, identify as dolomite, sandstone, and so forth. If the objective stratigraphic sequence of the rocks (if we are not dealing with an overfold or overthrust) corresponds to the true sedimentary sequence, this is only established by judgments which go beyond the objective local observational data. Basically there are here as many opportunities for error as in the time interpretation of fossils. Are not the collections of fossils which allow us to assign a rock group to a particular geologic age also objective material data?

The antithesis is, in my opinion, that we have to do, fron one point of view, with concrete rock strata and all their particulars while, from the other point of view, we are dealing with an abstract time scheme which is divorced from all local and regional influences. By this abstraction we gain a universally valid system of coordinates in which all the various occurrences and documents of geological history can be ordered and with which they can be measured.

I also think that the time units should not be defined by the time spans which are necessary for the laying down of the rocks but rather through the intimations of time which are available and which are brought out by the evolutionary changes of organisms which we use as time markers. Owing to their irreversibility they are true historical data which we in earth science have at our disposal and always shall have. And only when absolute age determinations shall become so accurate as to suffice for dating will there be a purely physical time scale without breaks in the history. But the latter must always arise when we merely place the individual epochs, periods, and eras on top of one another.

Thus series and systems are not ideal stratigraphic units as J. Rodgers [14] correctly maintains in opposition to Wheeler and other authors. They indicate rather rock bodies which are united with one another through their fossil content, which indicates their temporal unit.

Stratigraphy and chronology thus comprise two quite distinct categories, separated from the points of view of theory and definition, that in practice naturally have overlapping fields just as the fields of prostratigraphy and stratigraphy overlap. We need not pursue this subject further as I have earlier written more on the question.

Glossary

I propose now, in the remaining space, to deal with the terminology of the stratigraphic and chronologic units. This terminology was established, for the most part, by the early geologic congresses, though it has not always been strictly adhered to since. To avoid confusion one must follow the most essential of these resolutions.

In my opinion, and I have earlier [15, 16] published on this subject, one can make do with a relatively small number of terms. The flood of different names which sometimes, and with some confusion, overlap and sometimes are based on cavilling distinctions which cannot be effected in practice leads to confusion and is therefore worthless. Hedberg cites about 20 stratigraphic and chronological concepts; altogether I have counted over 50 terms which have been proposed as if this terminology was an end in itself and its extreme complication the ideal to be aimed at. This reminds one of the tremendously inflated and completely meaningless system of nomenclatural types before Rud. Richter brought order into this chaos with a few bold strokes.

As long as one is dealing with prostratigraphy, that is with units that cannot yet be validly defined as stratigraphic, unconventional appellations such as bank, beds, and group of beds, will have to suffice. Vague concepts need no single clear definition. Names such as Greenville beds or Greenville slates, Coral bank or Spirifer horizons have undoubtedly enough expressive power without putting more into them than they can contain.

One can also employ the expression "formation" according to the way that is customary in American writings, especially under the influence of J. Hall and J. W. Powell, once we accept a change in meaning from the original and broader sphere of the formational concept which was ascribed to it by its main proponents, G. Chr. Füchsel and A. G. Werner. The meaning of the expression "formation" is clearly bound up with the description primarily of the construction and constitution of the rocks and does not indicate a stratigraphic unit. For the sake of unity we would wish to follow the rulings of the international geological congresses and we must allow our hitherto usual usage of formation to lapse in favor of the word "system."

But we shall not, on that account, renounce the concept of "zone" which, in the hands of Hedberg, has become a quite unspecific term. The meaning of this concept is not to be clarified by a quotation from Webster's dictionary as Hedberg attempts to do, but through the scientific tradition by reference back to D'Orbigny and Oppel, the chief originators of the zonal concept. For their part I believe [15] I have adequately established that Oppel's zonal system had an abstract and clearly temporal character which was based on the life span of key species or on the sequence

of fauna. More recently Teichert [20] has also occupied himself with the zonal concept and recommended a return to its original meaning. It seems to me however that this exposition of Oppel is not conclusive as he sees in the zone a time-stratigraphic unit.

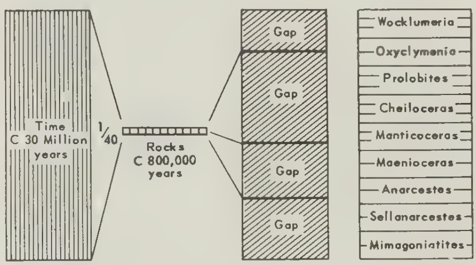
Oppel [12] formulated the aims of his zonal classification unequivocally as follows: "disregarding the mineralogical constitution of the rocks to investigate the vertical extent of certain particular species at the various localities." The result produced "an ideal profile whose members of various ages in the various regions are always characterized by the same species." These ideal profiles were abstracted from all qualitative and spatial characteristics of the sedimentary strata and what remained after this abstraction of the common element of the various rock members was the temporal component.

I therefore categorically believe that I should intercede for the maintenance or rather the return to the zone concept with a purely chronological meaning. I do not do this out of a spirit of disputatiousness as I have already taken my stand in the past on the same basis. I am also sympathetic towards the other interpretation which would derive a stratigraphic implication of the concept from D'Orbigny's use of zone, which however is not so clear as Oppel's. It really doesn't matter which aspect of a concept becomes accepted by agreement; the main point is that it should be unequivocal. But here we run into the further fact that most of the zones in general use are distinguished by guide fossils. But a zone of Macrocephalites macrocephalus can only have meaning as a time character, namely the life span of the named species. The name has no connection with strata and is thus not a stratigraphic term.

"Time span" of a species is not something that can be established too strictly. The cases in which a species "a" changes into species "b" and goes over to it completely are comparatively rare. Generally species "b" is to some extent branched off laterally from "a" so that both species live next to each other for a certain length of time. The zonal boundaries are then so arranged that they are based on the replacement of the older species and take as their criteria the generally strong influx of the new species which chronologically follows the older. In such cases therefore the actual life span is not implied but more correctly the range of its prime, as Buckman has previously emphasized.

As a pure time concept naturally the zone is universal, that is, the time content of the Macrocephalites macrocephalus zone is also present when, in a local section, the zone fossil is absent owing to the nature of the facies. It has, in this abstract-time sense, in no way a "more or less restricted horizontal extent" [8].

It is often stated that the zonal boundaries are generally marked by (stratigraphic or) time gaps [10]. In a particular section, rock-equivalents of the zones will often be truncated in this manner so that only partial zones remain. But in the broad view, that means to say taking into consideration all accessible outcrops and sections, our abstract zonal scheme is practically complete, with no noteworthy gaps. An extreme point of view has claimed that only about one-fortieth of the geologic record remains in the form of sedimentary rocks (H. Korn, 1938, G. Richter-Bernburg, 1950) the rest is present as lacunae and missing sediments. These assertions seem to me not to accord with observation. A simple graphic demonstration will show what I mean. From the upper part of the Lower Devonian to the Upper Devonian nine superzones based on cephalopods can be distinguished. Each falls into two or three zones so that altogether there are about 20 zones. We ask ourselves how many of these would be realized in a given profile if that claim was true. The answer is given on the accompanying diagram in which the rocks are displayed which represent one-fortieth of each time. We would thus only encounter once here and there a measly chance slice of the zonal succession.



But the reality is quite different. A more or less full sequence of the zones and superzones is to be found whenever the cephalopod facies is well developed: in the German Mittelgebirge, Karnian Alps, the Pyrenees of southern France, the central mountains of Poland, the Urals, Novaya Zemlya, Kazakhstan, North Africa, and western Australia. A small part of it is also found in North America and China. It is obviously out of the question that the interruptions or sedimentation took place everywhere in the world at the same time, namely at the boundaries of the zones and the superzones which we have established. Of course, they must contain insignificant lacunae which will never be detected by paleontological means, but larger interruptions would lead to the collapse of the whole series of zones and superzones. It is quite true that the entire zonal sequence is not found in all the named outcrops. Occasionally only some of them are developed in a cephalopod facies, but then between them are found, not sedimentary lacunae but, in place

of the cephalopod-bearing rocks, sediments of another facies with other faunal groups. Here, therefore, is no time gap but only a break in the continuity of the deposition of the cephalopod facies. Synonyms of Oppel's zone include biozone, biochron, hemera (proposed by Buckman as the chronological expression of Oppel's zone to which he gave a stratigraphic and spatial meaning), phase, moment, and secule, but we do not wish to and cannot at this time go into all the individual names; it will suffice if at the end of our considerations we summarize them in the form of a table.

What the designation of the indivudal stratigraphic units (stage, superstage, series, systems) has to do with, in my firm opinion, is most suited to a geographic nomenclature, which as far as possible should be connected with the old adopted names and supported by new publications based on carefully selected sections. Correction of boundaries, refinement of boundaries, and selection from older, less exact, definitions must in the process naturally be permitted. On the priority standpoint in stratigraphy I have gone thoroughly into this subject in previous publications [15]; Richter [13] has recently gone into the matter thoroughly.

The fundamental chronological units should be given the name of the appropriate category to which they belong in the hierarchy. They are thus paleontologically characterized. The lowest category (apart from the subzone) is the Zone, for example the zone of Cheiloceras subpartitum (Mstr.). The next higher unit forms in Cheiloceras age, which would be its name in keeping with the spirit of the decisions of the early congresses or perhaps it would be better known as the Cheiloceras superzone in order to bring the one expression into relationship with the other. In English writings (for example those of L. F. Spath), they employ the useful expressions Cheiloceratan and Gyronitan. The introduction of these short names in German in the forms Cheiloceratium, Gyronitium should be considered.

From the epoch onwards the chronological nomenclature coincides with the stratigraphic nomenclature. One can as well speak of an Upper Devonian epoch, a Devonian period, and so forth as we speak of the Upper Devonian series or the Devonian system. In most cases one can drop the identifying termination which in general adds nothing to the meaning. When I speak of the saurians which lived in the Cretaceous that obviously refers to the Cretaceous period. On the other hand when I say the Cretaceous is very extensive in northern Germany then it is obvious that the rocks of the Cretaceous system are meant. This double meaning of the name should be no disadvantage. It symbolizes the similar coherence of geologic time and the products of earth history.

The Paleozoic, Mesozoic, and so forth are self-defined as eras of organic evolution, time concepts, but can without more ado also be used for the respective stratigraphic units (group or erathemes). Likewise Cryptozoic and Phanerozoic are eons with a time significance but can also without effort be transferred to the corresponding stratigraphic complexes [9].

The fundamental elements of geologic time

	Prostratigraphy	Stratigraphy	Chronology
Problem	Description and preliminary arrangement of the beds without attention to the time factors as regards rocks: Petrostratigraphy As regards fossils: Ecostratigraphy	Time sequence and correlation of the beds	Erection of a system of coordinates abstracted from concrete beds
Scope	Petrogäikum (Cryptozoic) and parts of the Biogäikum which have not yet been elucidated	Biogäikum	Phanerozoic
Terminology of the units	Group (Schictengruppe) Formation, rocks, roches (Schichten) Member (Schichtglied) Bed, layer, banc, strate (Bank)	Complex (Komplex) Group (Gruppe, erathem, groupe) System (Formation, systèm, terrain) Series (Serie, Abteilung, série) Superstage (Superstufe, superétage) Stage (Stufe, étage) Substage (Substufe, sousétage)	Eon (Äon, éons) Era (Ära, ère) Period (Periode, période) Epoch (Epoche, époque) Superzone (Alter, superzone, age, âge) Zone (Zone, biozone) Subzone (Subzone, souszone)

form the zone and the superzone or age. They serve the purpose of correlation: the zones are used for exact and detailed correlation while the superzone is used more for rather rougher, free-ranging intercontinental correlation or in cases where detailed zonation cannot be carried out. This separation of zones from superzones justifies their respective nomenclature with names of species on the one hand, genera on the other. All chronological units are thus composite structures of zones and superzones in hierachic degree. The boundaries of these higher units are defined by, and bound to, zonal boundaries. Likewise of course we can use the stages and superstages for correlation into which the zone-time is geographically transposed. That is to say, after we have arranged our zonal systems into a standard section in which the zones and superzones in question are spatially and materially realized. We can then thus set the stages and the superstages in their exact and precise time stratigraphic sense. The pia-stufe introduced by L. Seitz [18] must be ranged with the superstage in this sense - a paleontologically determined stratigraphic concept.

In practise it hardly makes any difference whether we speak of the correlation and zonation of the Manticoceras age (Manticoceratan) or of the Adorf superstage, both of them have a time significance. However the two terms belong to two separate systems of nomenclature. A geologic map, for example, does not show Manticoceras time but the rocks of the Adorf superstage.

SUMMARY

A subcommission for stratigraphic terminology was set up by the XIX International Geologic Congress in Algiers within the framework of the Stratigraphic Commission. Hedberg, as secretary of this subcommittee, invited the members to a discussion on the matter and set before them a memorandum which he had prepared as the basis of discussion. In order to contribute to the work of this committee, the present writer has summarized his point of view on certain fundamental concepts and terminological and nomenclatural problems of stratigraphy. According to his understanding, three systems of terminology have to be distinguished: 1) Prostratigraphy, preliminary stratigraphy without consideration of the time factor; 2) stratigraphy which is unconditionally bound up with time; 3) chronology, which sets up an absolute time scale without reference to concrete beds and their correlation. Petrostratigraphy (lithostratigraphy) and ecostratigraphy are assigned to prostratigraphy and they cannot yield any absolutely valid stratigraphic units. There, also, belong the 'biostratigraphic classification' in Hedberg's sense. The zone is defined as a chronological unit; it is thus restored to the original meaning given to it by Oppel.

REFERENCES

1. Arkell, W. J., STANDARD OF THE EUROPEAN JURASSIC: Geol. Soc. America, Bull., v. 57, p. 1-34, 1946.

2. Chadwick, G. H., SUBDIVISION OF GEOLOGIC TIME: Geol. Soc. America, Bull., v. 41, p. 47-48, 1930.

3. Hedberg, H. D., TIME-STRATIGRAPHIC CLASSIFICATION OF SEDIMENTATION ROCKS: Geol. Soc. America, Bull., v. 59, p. 447-462, 1948.

4. ________, NATURE OF TIME-STRATIGRAPHIC UNITS AND GEOLOGIC TIME UNITS: Amer. Assoc. Petrol. Geol., Bull., v. 35, p. 1077-1081, 1951.

5. ________, STRATIGRAPHIC TERMINOLOGY: XIX Congr. Géol. Int., Résumés, 1952, p. 112.

6. ________, PROCEDURE AND TERMINOLOGY IN STRATIGRAPHIC CLASSIFICATION: Unveröff, Mskr., 1952.

7. Henson, F. R. S., STRATIGRAPHICAL CLASSIFICATION AND NOMENCLATURE: Geo. Mag., v. 80, p. 166-169, 1944.

8. Jeletzky, J. A., DIE STRATIGRAPHIE UND BELEMNITENFAUNA DES OBERCAMPEN UND MAASTRICHT WESTFALENS, NORDWESTDEUTSHCLANDS UND DÄNEMARKS SOWIE EINIGE ALLGEMEINE GLIEDERUNGS-PROBLEME DER JÜNGEREN BOREALEN OBERKREIDE EURASIENS [THE STRATIGRAPHY AND BELEMNITES OF THE UPPER CAMPANIAN AND MAASTRICHT DEPOSITS OF WESTPHALIA, NORTHWEST GERMANY AND DENMARK, AS WELL AS SOME GENERAL CLASSIFICATION PROBLEMS OF THE UPPER CRETACEOUS OF NORTHERN EURASIA]: Beih., geol., v. 1, 142 p., 1951.

9. Kobayashi, T., CONCEPT OF TIME IN GEOLOGY: Imp. Acad. Tokyo, Prov., v. 20, p. 475-483, 742-750, v. 21, p. 70-77, 1945.

10. Moore, R. C., STRATIGRAPHY. In: GEOLOGY, 1888-1938, 50th Annivers. Vol. Soc. America, p. 197-200, 1941.

11. ________, STRATIGRAPHICAL CLASSIFICATION: Geol. Soc. Japan, Jour., v. 56, p. 39-47, 1950.

12. Oppel, A., DIE JURAFORMATION ENGLANDS, FRANKREICHS UND DES SÜDWESTLICHEN DEUTSCHLANDS [THE JURASSIC OF ENGLAND, FRANCE, AND

SOUTHWESTERN GERMANY]: Stuttgart, 1856-1858.

13. Richter, R., DIE PRIORITÄT IN DER STRATIGRAPHIE UND DER FALL KOBLENZIUM/SIEGENIUM/EMSIUM [THE PRIORITY IN THE STRATIGRAPHY AND SEQUENCE OF THE COBLENZIAN, SIEGENIAN, AND EMSIAN]: Senchkenbergiana, v. 34, p. 327-338, 1954.

14. Rodgers, J., NATURE, USAGE, AND NOMENCLATURE OF STRATIGRAPHIC UNITS: A MINORITY REPORT: Amer. Assoc. Petrol. Geol., Bull., v. 38, p. 655-659, 1954.

15. Schindewolf, O. H., GRUNDLAGEN UND METHODEN DER PALÄONTOLOGISCHEN CHRONOLOGIE [FOUNDATIONS AND METHODS OF PALEONTOLOGIC CHRONOLOGY]: Berlin, 1944.

16. ________, GRUNDLAGEN UND METHODEN DER PALÄONTOLOGISCHEN CHRONOLOGIE [FOUNDATIONS AND METHODS OF PALEONTOLOGIC CHRONOLOGY]: Berlin-Nikolassee, 1950.

17. ________, DER ZEITFAKTOR IN GEOLOGIE UND PALÄONTOLOGIE [THE TIME FACTOR IN GEOLOGY AND PALEONTOLOGY]: Stuttgart, 1950.

18. Seitz, O., DIE OBERKREIDE-GLIEDERUNG IN DEUTSCHLAND NACH IHRER ANPASSUNG AN DAS INTERNATIONAL SCHEMA [THE CLASSIFICATION OF THE UPPER CRETACEOUS IN GERMANY ACCORDING TO ITS ADAPTION TO THE INTERNATIONAL SCHEME]: Z. Deutsch. Geol. Ges., v. 104, p. 148-151, 1952.

19. Simon, W., ZEITMARKEN DER ERDE. GRUND UND GRENZE GEOLOGISCHER FORSCHUNG [TIME MARKERS OF THE WORLD. INVESTIGATION OF SEDIMENT AND GEOLOGIC LIMITS]: Die Wissenschaft, v. 98, 1948.

20. Teichert, C., ZONE CONCEPT IN STRATIGRAPHY: Amer. Assoc. Petrol. Geol., Bull., v. 34, p. 1585-1588, 1950.

21. Wheeler, H. E., and others, STRATIGRAPHIC CLASSIFICATION: Amer. Assoc. Petrol. Geol., Bull., v. 34, p. 2361-2365, 1950.

22. Wheeler, H. E., and V. S. Mallory, DESIGNATION OF STRATIGRAPHIC UNITS: Amer. Assoc. Petrol. Geol., Bull., v. 37, p. 2407-2421, 1953.

23. Woodring, W. P., STRATIGRAPHIC CLASSIFICATION AND NOMENCLATURE: Amer. Assoc. Petrol. Geol. Bull., v. 37, p. 1081-1083, 1953.

THE RELATIONSHIP BETWEEN EXPLORATION, SURVEYING, AND PROSPECTING [1]

by
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• prepared by the United States Joint Publications Research Service •

ABSTRACT

The end purpose of all geologic field work in the U. S. S. R. should be the detection of useful mineral resources necessary to the Soviet national economy. At the present time, unfortunately, the numerous guides, instructions, and manuals on the methods of geologic surveying, prospecting, and exploration do not clearly define the nature and tasks of each form of geologic investigation. The various guides, at times, overemphasize their own discipline to the detriment of a related phase of geologic investigation or, conversely, so identify one discipline with another that the role of each is not quite clear.

The present practice of a large-scale survey followed by a medium-scale survey, and then by a small-scale survey is time consuming and expensive. There is no reason why a survey on a 1:200, 000 or 1:100, 000 scale should always be followed by a survey on a 1:50, 000 or 1:25, 000 scale and only then by a survey on a 1:10, 000 scale. Proper instruction of the field geologist would improve the quality of such surveys so as to insure transition to another scale without necessitating additional surveys. The field geologist would then have a greater responsibility for the quality of his work and for the care taken in prospecting in a region.

To achieve this goal it is necessary to revise all the instructions on geologic surveying, to unify all prospecting methods in these instructions, and to define accurately the role of geologic surveying in relation to prospecting and exploration. --T. F. Rafter, Jr.

All geologic work undertaken by the organizations of the Ministry of Geology and Conservation of Mineral Resources, U. S. S. R. , should be oriented and subordinated to the goal of detection and prospecting exploration of the sites of useful minerals necessary to the Soviet national economy.

In this connection, the numerous guides, instructions, and manuals on the methods of geologic surveying, prospecting, and exploration of mineral resources do not include any pertinent definition of the nature and tasks of each of the above forms of geologic investigation. In the guides and instructions geologic surveying is compared in importance with geologic prospecting and identified with it or, conversely, contrasted with it. Frequently, tasks inherent to prospecting work proper are ascribed to geologic surveying. In some cases, prospecting and surveying are combined into prospecting-surveying work, in which connection the role of each in this "complex" is not quite clear. Frequently, the definitions of the tasks of geologic surveying ignore the need for activities directly purporting the discovery of mineral resources as part of the investigation of the prospects of a given region.

The uncertainty in understanding the nature of geologic surveying may, in my opinion, be exemplified by a book issued by the All-Union Scientific Research Institute of Mineral Raw Materials under the title of "On the Methods of Geologic Surveying at Prospecting and Exploration of the Sites of Mineral Resources," published by the Gosgeoltekhizdat Press in 1955. On page 3 of that book it is pointed out that a large-scale geologic survey, meaning a survey on the scale of 1:50, 000 and more, ". . . can not be regarded merely as a method of prospecting." From this it may be concluded that such a survey is to some extent a method of prospecting work. But on page 4, it is stated that " . . . the large-scale geologic survey is to be defined as the fundamental method of studying ore fields and sites for the purpose of providing a foundation for a rational exploration, quantitative determination, and exploitation of the deposits." In the given case the importance of such a survey to prospecting is no longer mentioned despite the well-known importance of large-scale geologic surveying as a method of prospecting for mineral resources in specific conditions, especially with regard to well hidden but promising deposits.

On page 11 of the above book, in contrast, it is stated that "Large-scale geologic charts serve primarily as a foundation for resolving the problems relating to the prospecting for and exploration and exploitation of deposit sites . . . " On page 4 the reader is warned that " . . . the identification of a large-scale survey with the prospecting work which, of course, should be included as a required part of the surveying work, may considerably narrow and curtail the scope of the large-scale surveying work." Now we find that prospecting is a "part" of geologic surveying. Such a confusion in the definition of the

[1]Translated from Razvedka i Okhrana Nedr, 1958, no.9, p. 11-14.JPRS (NY) L-679-N.

principal concepts which should guide the geologists in their practical activities is completely impermissible.

In the "Methodological Guide for Geologic Surveying and Prospecting" compiled by the All-Union Geological Scientific Research Institute and published by Gosgeoltekhizdat in 1954, it is stated on page 9 that " . . . the geologist should be enabled by the results of a geologic survey on the scale of 1:50, 000 to 1:25, 000 to provide a long-range estimate of the dimensions and importance of the undiscovered mineral resources and also to determine the boundaries of the areas subject to detailed prospecting or prospecting-exploring work. " In this case the tasks of geologic surveying and prospecting are completely identified with each other.

The same guide, on page 6, attempts to provide a general definition of the tasks of geologic surveying without differentiating among its special characteristics: "The principal purpose of the geologic survey is to appraise the perspectives of a region in regard to its mineral raw material resources. " Such a definition, aside from its being applicable only to small-scale surveys, attributes to the geologic survey tasks that can be resolved reliably only through the application of the overall whole of prospecting activities, and it fails totally to characterize the relationship between geologic surveying and prospecting and exploration.

A fundamental shortcoming of the above-cited and similar definitions of the nature and purposes of geologic surveying is, in the author's opinion, the absence of relevance in properly orienting the field geologists to the execution of their principal task, the detection and appraisal of the sites of mineral resources.

The influence of this shortcoming on practical work proves to be extremely essential. The absence of purposefulness in geologic work results in the failure to observe the condition of omnilaterality in surveying, in the underestimation of the geologic chart when prospecting and exploring, in the purposelessness of many research and thematic activities, and in the violation of the condition of a pertinent order of sequence in the execution of work and exploration of regions.

A major drawback with regard to geologic surveying is, in this writer's opinion, the excessive emphasis placed on the importance of a sequential conduct of work on different scales. Obviously, the investigation of the geologic structrue of this or that region should be conducted on a more detailed scale. But there is really no reason why a survey on the 1:200, 000 or 1:100, 000 scale should necessarily always be followed by a survey on the 1:50, 000 or 1:25, 000 scale, and only thereafter by a survey on the 1:10, 000 scale. There are regions with well-defined outcrop features where medium-scale surveys may be executed with reliability, and in such cases the field geologists should be advised to improve the quality of such surveys so as to ensure the transition, in subsequent studies, to a much larger scale without having to conduct surveys on the intermediate scales. In this way, it is possible to considerably hasten the investigation of a region and greatly reduce the expenditures of State funds and means.

The required observance of sequence in the execution of geologic surveys on different scales reduces the responsibility of the field geologist for the quality of the executed work and, especially, for the care taken in prospecting in a region. Thus the field geologist, expecting that his work will be followed by more detailed surveys, does not attempt to complete his exploration of the region, and merely confines himself to recommendations of a general nature in accordance with the requirements of the instructions for a given scale, on the assumption that someone else will use his recommendations to prospect for the deposit sites which he himself has bypassed.

Inasmuch as the principal purpose of the Geological Service is the discovery and industrial appraisal of the sites of mineral resources, the principal goal of all geologic organizations, and of every geologist, should be the execution of prospecting and exploring activities. All geologic investigations and measures should be subordinated to this goal, and the principals of such investigations and measures, such as the geologic, metallometric, and schlich work, the gamma survey, core and hand drilling, mountain-tunneling work, and others, should be regarded as elements of prospecting and exploration. Consequently, geologic surveying should, together with the other methods, play a secondary role compared with prospecting and exploration, in this writer's opinion. If the purposes of geologic surveying are conceived otherwise, they lose their relevance, and geologic surveying becomes "surveying for surveying's sake, " which is of very little value to the prospecting for utile minerals.

The degree of the dependence of geologic surveying or prospecting tasks differs depending on the scale of the survey. Regional geologic surveys on the scale of 1:1, 000, 000 to 1:500, 000 should be intended for compiling multipurpose geologic charts. With regard to prospecting, such charts are suitable only for the most general representations about the individual-mineral perspectives of separate large regions. A medium-scale geologic survey on the scale of 1:200, 000 to 1:100, 000 may, as demonstrated by practice, reveal large industrially exploitable sites of utile minerals. In this case, the geologic survey is indubitably a method of prospecting serving to ensure prospecting with factual data of utmost value.

In the light of the above, the nature and purposes of medium-scale geologic surveys may be defined as follows: medium-scale geologic surveys are the cardinal method of prospecting work on a corresponding scale intended to uncover the sites of utile minerals and to appraise the prospects for their discovery on individual sections of the region under study. Large-scale detailed geologic surveys on the scale of 1:50,000 to 1:500 have an additional special purpose. In geologic work proper they are applicable, for an overwhelming majority of cases, solely to insure prospecting and exploration work. Therefore, it would not be erroneous to regard them as a method of prospecting and exploration work.

In a large-scale survey, major importance is acquired by metallometric work, which makes it possible to discover even the buried ore sites. In prospecting and exploration, the role of drilling and mountain-tunneling work is increased. The nature and purposes of detailed geologic surveys may be thus formulated: detailed geologic surveys are a necessary method of large-scale prospecting and exploring work purporting to uncover new sites of mineral deposits, to clarify the long-range prospects of known sites and ore fields, and also to provide a geologic-economic estimate of the explored sites. In this way, only the regional geologic surveying work may be said to be to some extent independent. In the remaining cases, geologic surveys should be a component part of prospecting or exploring work.

It should be noted that in present-day practice that, in the evaluation of geologic charts, the degree of their value for prospecting is very often ignored; in particular, no requirements are posed for the consideration of such elements of geologic structure, directly related to prospecting, as: manifestations of contact and hydrothermal metamorphism, morphology of intrusive bodies, and structure of the weathering crust.

Prospecting can be successful only when it is conducted omnilaterally, by applying all the methods possible in a given case. Here, such methods should be closely interrelated in their use so as to complement each other effectively. Prospecting tasks may be successfully expanded only on collating the totality of the obtained field data, but for this purpose all the measures taken at prospecting should be oriented toward one single goal: the uncovery of the sites of mineral deposits. On the basis of the above statements, the nature of prospecting may be defined as follows: prospecting work constitutes an interrelated complex whole of geological measures and undertakings every one of which and all of which as a whole are oriented toward the discovery of the sites of utile minerals and their preliminary evaluation.

Approximately the same may be said about exploration work. Like prospecting, exploration should be carried out on the application of the complex whole of measures serving to achieve a fundamental goal. The nature of exploration may be defined as follows: exploration work constitutes an interrelated complex whole of geologic and technical measures every one of which and all of which as a whole are oriented toward clarifying the economic value and long-range prospects of a deposit site and the mining-engineering conditions for its exploitation.

CONCLUSION

It is necessary to dwell on the problem of the conduct of geologic surveying proper, as isolated from the prospecting goal. As can be seen from the above, the execution of geologic surveys, except for the regional surveys, is inexpedient if done without an appropriate prospecting or exploring purpose. Whatever the geologic survey, it should always purport to reveal deposit sites and it should always be executed as part of a complex whole of prospecting methods to be applied to an extent adequate for a reliable prospecting study of a territory on a given scale, and not in isolation from these methods. If this condition is not observed, the geologic survey inevitably acquires a one-sided importance and approximates "surveying for surveying's sake," and thus most of its results become valueless. In my opinion, geologic surveys should henceforth be allowed only if accompanied by the complex whole of the measures ensuring the compilation of a full-value conditional geologic chart.

To achieve this goal it is necessary to revise all the instructions on geologic surveying, to unify all prospecting methods in these instructions, and to define accurately the role of geologic surveying in relation to prospecting and exploration. From these instructions it is necessary to exclude any possible unclear concepts, such as the concepts of surveying-prospecting work or of geologic surveying based on prospecting work.

It is also necessary to modify the work on the compilation of a medium-scale State geologic chart. Such a chart would not satisfy the modern practical requirements if it were to be prepared without considering its prospecting aspects. Even then, however, it could not serve as a foundation for more detailed prospecting, because this would necessitate that the schlich, metallometric and metallogenic charts be on a corresponding scale - without these last-named charts there is the likelihood of making erroneous conclusions, organizing further prospecting improperly, and expending labor and State funds uselessly.

Therefore, the compilation of medium-scale State geologic charts should absolutely be accompanied by a parallel work on the compilation of conditional schlich, metallogenic, metallometric, and gamma-activity charts, on the scale of the

geologic chart, and, for the appropriate regions, also geophysical charts. All this work would require the drafting of instructions and the standardization of the nominal definitions.

Notes on international scientific meetings

SUMMARY OF REPORTS PRESENTED AT THE CONFERENCE ON THE PROBLEM OF THE ORIGIN OF OIL AND THE FORMATION OF OIL DEPOSITS [1]

Baku, U. S. S. R. 1958

edited by

M. V. Abramovich and Sh. F. Mekhtiyev [2]

• translated by Paul T. Broneer •

Mekhtiyev, Sh. F., and N. A. Yeremenko, THE PRESENT STATUS OF THE PROBLEM OF THE ORIGIN OF OIL AND THE FORMATION OF ITS DEPOSITS. Today's views on the problem of the origin of oil and the formation of oil deposits have their source in the work of the last hundred years. The two basic, contrasting trends, the organic and the inorganic origin of oil, made their appearance in the 19th century. From these ideas came many hypotheses and theories, some of which have gained wide recognition in recent years.

There are two possible ways of solving the problem of the origin of oil:

1. By establishing a chemical scheme of the formation of hydrocarbons and verifying it experimentally under conditions of formation of oil and gas deposits, some solutions may be found. But, one must not assume any identity between oil and hydrocarbons formed through inorganic synthesis. In the composition of oil there are substances which have a biogenic origin.

2. By studying empirically the distribution of deposits in the earth's crust with the purpose of reconstructing their geologic and geochemical history and selecting the chemical scheme that conforms to it.

Both methods are fruitful. Up to now the first has enjoyed by far the greater popularity; as a result, many different possibilities for the formation of hydrocarbons have been discovered. In the present state of our knowledge preference is rightly given to the theories and hypotheses of the organic origin of oil. A considerable number of the schemes of hydrocarbon formation appear to correspond to conditions in the earth's crust. Many hypotheses of the formation of oil and oil deposits were made by inference. In attempting to solve the problem by establishing chemical schemes of hydrocarbon formation, the basic task is to establish the possibility that oil and gas deposits could be created from hydrocarbons formed by various means.

At the present time the following ideas are solidly established: 1) that it is possible for hydrocarbons to be formed inorganically, but that it has not been proved that deposits of oil can be created from hydrocarbons formed by inorganic means; 2) that hydrocarbons can be formed from various organic compounds by various means and under various conditions; and 3) that it is possible for organic matter in rocks and sediments - both disseminated and concentrated - to be transformed with the formation of hydrocarbons.

The connection between organically and inorganically derived hydrocarbons and other components in oil and gas deposits, and also the mechanism by which deposits are formed, must be made clear in chemically solving the problem.

Two ways of solving this question have been conceived: 1) discovery of properties and ingredients in the composition of the substances being studied that would unquestionably establish their genetic relationship; and 2) discovery of the ways by which oil and gas deposits could be formed from hydrocarbons originating in various ways.

Up to now, the latter trend has been based chiefly on inference and partly on experiments and observations of migration. The former trend always meets with the objection that oil and gas can acquire this or that property only during the process of formation of oil and gas deposits.

If the first method of solving the problem can be conditionally called the chemical, the second can rightly be called the geologic and geochemical. The formation and distribution of deposits of any useful mineral are very closely connected to the development of the earth's crust. This is equally true of such minerals as oil and gas. In an examination of their distribution in the earth's crust from the view point of geologic history, the circumstances of their formation must inevitably come to light. For this very reason, the study of oil and gas distribution in the earth's crust (in non-commercial accumulations, commercial deposits, regional zones, interconnected deposits, basins, or provinces of oil formation) is of primary importance. To this it must be added that the discovery of these conditions is of great practical importance in searching and prospecting for such minerals. The fundamental task here is not only to study such conditions individually, but to discover both the connection between them and the

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[1] Translated from Soveshchanyye po probleme proiskhozhdeniya nefti i formirovaniya neftyanykh zalezhei: I. M. Gubkin Institute of Geology, Azerbaidzhan SSR, Baku, 1958.

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whole process of development of the earth's crust. Analysis is still the most important element in studying this problem: individual cases are being discovered, studied, and analyzed. But the time has come to proceed from analysis to synthesis: from the detailed study of individual phenomena to their dialectic correlation. Among the most important conditions that have been established, the following can be noted:

1. The definite, regular connection between oil and gas deposits and sedimentary strata, and their infrequent, unique, sporadic, or chance connection with other geologic formations. Chance is here understood as one form of necessity stemming from the concrete geologic conditions.

2. The regular connection of oil deposits with basins of sedimentary accumulation. This connection, though long established, has been insufficiently investigated. The types of sedimentary basins with which oil and gas deposits are connected appear to be those situated in zones of transition from platforms to geosynclines. Perhaps it would be correct to consider such zones as huge, independent geologic structural elements, on a level with platforms and geosynclines. Basins developed at the margins of platforms also appear to be favorable for oil. But the possibility that the process of oil formation could be widespread in intracratonic basins is doubtful for even such a classic example of this as the Michigan basin in the United States can, in the lower Paleozoic, be considered as marginal. It must be noted, however, that oil deposits in a number of regions in China are connected with intracratonic basins. There is no doubt that the processes of oil formation can take place in geosynclinal sedimentary basins, but the question of the formation and destruction of the oil and gas deposits within them, in the context of their historical development, still requires substantial study.

3. A number of circumstances in the accommodation of great zones of oil and gas accumulation within basins has been noted. We shall not dwell upon these.

4. One can point out a definite cycle or periodicity in the distribution of oil and gas deposits, both in individual basins and in the earth's crust as a whole. Evidently L. V. Pustovalov's idea of the connection between cycles of oil formation and cycles of sedimentary accumulation can be profitably developed.

Only the most important general conditions of the distribution of deposits in the earth's crust have been mentioned above. What path should be taken to unite them (synthesizing them) into a single, dialectic whole? To us it appears that such a unity, such a correlation between the conditions that have been discovered can be established within the context of the geologic history of the earth's crust. We must relate to cycles of sedimentary accumulation and cycles of oil and bitumen formation. We must also establish the connection between the latter and the tectonic development of the earth's crust, particularly the phases of tectogenesis.

Little has yet been done in this direction. But the already existing materials on the northeastern and southeastern Caucasus make it possible to mark a certain regularity. Evidently the moments of geologic history most favorable for the processes of oil and gas formation are the periods intervening between the phases of tectogenesis. At the same time, periods of intensive tectogenesis are most favorable to the migration, formation, reformation, and destruction of oil and gas deposits.

Fedorov, S. F., THE FORMATION OF OIL AND GAS DEPOSITS. The structural details of each oil- and gas-bearing region are different. Structural peculiarities have affected the formation of oil and gas deposits. Comparative study of the conditions under which the oil and gas deposits of various regions were formed, however, has made it possible to establish general as well as particular features.

The Ukhta deposits, for example, situated on the slope of the Timan ridge, contain within Devonian sediments only oil which is of a very thick consistency. The Voivozh deposit, to the southeast and hypsometrically lower than the first one, contains both oil and gas in Devonian rocks. Along the side of the Pechersk depression, the Nibel deposit in Devonian strata contains only gas.

In the light of the factual material on the distribution of the oil and gas deposits in the Ukhta region, the following sketch of the formation of these deposits can be made. Oil and gas were formed in the Pechersk depression. They migrated upward along the regional rise in the beds and filled structural traps with oil and gas. As is known from the works of V. P. Savchenko, V. K. Gassou, and other investigators, traps that are filled with gas can no longer serve as traps for oil. Thus the first structures in the path of the migration of the oil and gas became filled with gas alone; the next with gas and oil; and finally, the last ones in the regional upward rise of the strata only with oil.

A similar picture of the formation of oil and gas deposits can be observed in the Kuybyshevskaya region of the Volga. In the Samarskaya Luka area, from east to west, the following deposits are situated in the coal-bearing suite: the Solyanoy ravine with oil having a specific gravity of 0.81; the Strelnaya, 0.848; the Zhigulevsk, 0.856; the Yablonka ravine, 0.890; the Berezovaya, 0.859; the Karlovka-Sytovka, 0.862; the Gubina, 0.878; the Syzran, 0.883; and the Zaborov, 0.891.

The lightest oil with the highest gas factor is contained in the Solyanoy ravine deposit, and the heaviest is in the west, in the Syzran and Zaborov deposits. The only exception to this regular distribution of the oil is the Yablonka ravine deposit. But we have already explained this exception in 1952 in one of our published works: the Yablonka structure was formed a little later than those around it.

The distribution of oil in all the deposits of the Samarskaya Luka area is thus completely regular: the lightest oils, saturated with gas, are located in the east, while the heaviest oils are in the western and most elevated part. If we add the Pokrovka structure, south of Samarskaya Luka, with oils whose carbon has a specific gravity of 0.800 and the group of deposits of the Sergiyevsk region with oils in the coal-bearing suite of a specific gravity of 0.900 and higher, the picture of the formation of these oil and gas deposits will be the following.

We already noted in 1954, that the collecting area for most of the oil in the Kuybyshevskaya region of the Volga is the northern Caspian depression. The oil and gas, moving upward along the regional rise in the bedding, first saturated the Pokrovka deposit, then the eastern part of Samarskaya Luka; finally the structures in the western part of Samarskaya Luka and the Sergiyev region were saturated with heavy oil lacking gas. The Mukhanovo structures were in a position analogous to the structures of the eastern part of Samarskaya Luka, or else were situated even more favorably for oil and gas saturation.

The oil and gas deposits of the Saratov region of the Volga were formed under similar circumstances. In an article published together with A. I. Kutukov in 1950 we presented their general features; our suppositions have now been fully confirmed. Thus, in Sokolov mountain, we have in Devonian sediments oil without a gas cap, while in the Trans-Volga area to the east, in the northern Caspian depression, the Stepnoy deposit contains gas with oil in the same Devonian sediments. The same correlation can be seen in the coal deposits (Yelshanka and the structures south of Saratov).

The deposits of oil and gas in the Kuban were formed in a similar way. The structures located nearest the center of the Kubano-Priazovskaya depression (the Frunze deposits) are saturated with gas; farther to the south, toward the Caucasus ridge, the structures (the Slavyansk deposit) contain gas with indications of oil; still farther south the structures (the Anastasiyev deposit) contain gas with oil of industrial grade; and the southernmost structures, in the Caucasus foothills, contain only oil (the deposits of the Crimean region).

This regularity can also be traced in many areas of Azerbaidzhan, for example along the line: Binagady-the Lenin district-Surakhany-Karachukhur-Peschany island, Surakhany-Kala-Gousan, Kergez-Puta-Lokbatan. There is a similar phenomenon in western Turkmenia, for example along the line: Kyzylkum (gas)-Kum-Dag (gas and oil)-Boyadag (remains of a thick oil).

Thus, in a series of oil- and gas-bearing regions of the Soviet Union, one observes the following regularity in the formation of oil and gas deposits. Oil and gas are formed in zones of depression. In the movement upward along the regional rise in the bedding, the first structures in the path of oil and gas migration are saturated with gas, the next structures with gas and oil, and the last with oil. In other words, in the regions noted, deposits of oil and gas are formed according to differential trapping.

This regularity in the formation of oil and gas deposits can serve as a guide in the search for new deposits. If, for example, in the Kuban depression, south of the central zone of the flexure, the presence of gas, then gas and oil, and finally oil deposits is established, then, by the law of inversion, there will be a similar regularity in the distribution of oil and gas deposits in the northern side, if the facies and structures there are analogous. The same thing will take place in other regions.

Veber, V. V., OIL-BEARING ROCKS, THEIR FACIES TYPES AND THEIR FORMATION. Oil-bearing rocks are associated with definite sedimentary facies and are characterized by a definite granulometric composition and geochemical properties. The granulometric and geochemical indices of groups of oil-bearing terrigenous rocks (sandstones, siltstones) can be compared with the corresponding indices in contemporary sediments. Chief among these facies types which can be distinguished in this comparison are: a) sands and silts of marine shorelines, b) deltaic sands and silts, and c) sand and silt facies of lagoons and half-enclosed gulfs of the sea.

The circumstances of formation of the sand-silt sediments of each of these facies types allow the possibility that the organic matter from which oil originates can accumulate in such sediments and later be altered in the direction of oil. Data on Quaternary bitumen formation allow us to consider this possibility as fully realistic and natural.

Study of the conditions of oil formation is greatly aided by quantitative and qualitative comparison of the bituminous components in oil-bearing rocks and the components interbedded with them in various oil-bearing suites.

Brod, I. O., THE CONDITIONS OF FORMATION OF OIL AND GAS ACCUMULATIONS IN THE

EASTERN CIS-CAUCASUS. The western part of the eastern Cis-Caucasus consists of the huge middle Caspian oil- and gas-bearing basin which is filled with a thick series of Mesozoic and Cenozoic sediments. In the series of sedimentary rocks composing this basin, a series of lithologic-stratigraphic complexes of Middle Jurassic, Lower Cretaceous, Paleogene, and middle Miocene age can be distinguished. In addition, the carbonate series of the Upper Jurassic, the Lower and Upper Cretaceous, and the foraminiferous strata can be considered as regional oil- and gas-bearing rocks.

The formation of zones of oil and gas accumulation, and the oil and gas deposits associated with them, differ at the folded margin of the basin where the foremost folds of the Caucasus are located and at the platform edge of the flexure where there is a zone of buried anticlines composed of Mesozoic sediments.

In the anticlinal zone of the foremost folds in the eastern part of the northern slope of the Caucasus, the oil-collecting areas are these individual folds, synclines, and zones of trenches in the foothills. The source of oil for the stratigraphic zones of gas and oil accumulation on the Black Sea monocline, and on the flanks and surrounding folds of the anticlinal zones, is also these same synclinal flexures. The oil-collecting areas for the zones of buried anticlines on the platform slope of the flexure are the foothill trenches, the Tersko-Sulak depression, and the synclines separating the anticlinal zones from each other.

The formation of deposits and of associated individual structural elements within deposits is determined, both in the foremost folds of the Caucasus and in the zone of buried anticlines on the platform slopes, chiefly by intraformational migration taking place freely within the reservoir rocks. Molecular migration within the reservoir rocks is important chiefly in the formation of deposits in the carbonate series. Free migration along faults within the reservoirs is of less importance in the formation of the known deposits in the Cis-Caucasus. Such ruptures, known in considerable number in the frontal folds of the Cis-Caucasus, cause the screening of the layered deposits.

The hydraulic factor plays a decisive role in the formation of deposits in numerous types of traps that are known in the anticlinal zones of the foremost folds of the Cis-Caucasus. Pressure and the direction of movement of the water are of basic importance both in the formation of individual deposits of oil and gas and in their retention in traps. In the anticlinal zones of the platform, deposits are formed chiefly through gravity; that is, by the upward flow of oil and gas along the inclination of the strata, with the formation in traps of both free and screened deposits. The differentiation of oil and gas in natural reservoirs is determined by the cumulative action of a whole group of structural, hydrogeologic, and physical factors.

The difference in the formation of oil and gas accumulations in the eastern Cis-Caucasus are determined by the various kinds of structures that control the formation of traps in separate areas, and by the various types of natural reservoirs in which the circulation of water and the differentiation of oil and gas take place. These distinctions can be seen from an examination of the individual zones of gas and oil accumulation and the oil and gas deposits associated with them in each oil- and gas-bearing region of the Cis-Caucasus.

Gimpelevich, Ye. D., and A. A. Ilina, SIMILARITIES AND DIFFERENCES IN THE CHEMICAL COMPOSITION OF OIL AND DISSEMINATED BITUMENS. Complex investigations have been made of the chemical composition of the soluble part of the organic matter in the Tertiary sediments of the Stavropol and Krasnodar districts in comparison with the chemical composition of oils of the same age from the same province, using chemical-bituminologic and optical methods of investigation.

The reduced and acid components were studied separately. In investigating the hydrocarbon fraction, chromatography, annular analysis, and infrared and ultraviolet spectroscopy were used. The large-molecular and acid components were separated by specially devised methods and analyzed by the methods applied as above.

A comparison of the reduced portion of both types of fuel rocks has shown the physico-chemical similarity of oil and methane hydrocarbons, or the presence of the same class of hydrocarbons. Oil has a higher content of aromatic hydrocarbons and a lesser degree of cyclic recurrence than bitumens.

A characteristic distinction of the fraction of aromatic hydrocarbons separated from clay rocks of low bitumen content is the presence in them of the aromatic hydrocarbon perylene ($C_{20}H_{12}$) with five nuclei; it has not been discovered in the analogous fraction taken from oils and highly bituminous rocks.

Comparison between the acid fraction of bitumens and oils has shown the similarity of their organic acids and phenols (which were separated from the oils and bitumens by their elemental composition). Compared to bitumens, the acidity of carbonic acids in oils is lower.

Differences were found in the quality and character of the porphyrins in the fuel rocks under consideration. In the disseminated bitumens derivative chlorophylls, thiophytins, thiophorbides, and traces of free porphyrins were

found; whereas in the oils under investigation, the porphyrins were either absent or in the form of traces of the nickel complex of porphyrins.

The data obtained indicate that the chief source of accumulation of the oil hydrocarbons was organic matter disseminated throughout the rocks. The differences that have been noted in the composition of the oils and bitumens are explained easily by the adsorptive properties of the rocks.

Kudryavtsev, N. A., THE INORGANIC ORIGIN OF OIL. In spite of innumerable investigations, the "details," "clarified in essence long ago," of the transformation of organic matter remain as unknown as before. Those who assert the existence of this hypothetical process have not succeeded in explaining a single one of its important aspects (the causes producing it, the time when oil is formed, the chemistry of the transformation, and so forth); and the suppositions made in this regard are not supported by facts. The reason for this lack of success is that in nature such a process does not exist.

The process by which oil, formed from disseminated organic matter, is concentrated into deposits also remains entirely one of inference. Analysis of the question shows that such concentration cannot take place at all.

The notions of the organic origin of oil are fruitless in practice: the practical conclusions drawn from it are disproved.

The actual regularity in the distribution of oil and gas in oil- and gas-bearing regions is due to the fact that they are contained, beginning at any level, in all low-lying horizons including the crystalline basement in complete independence of the composition and conditions of formation of the rocks containing them. In those rocks in which collecting reservoirs and traps exist they form accumulations of industrial grade. The borders of oil-bearing areas do not correspond to the borders of any suites or rocks at all; this confirms their independence from the conditions of formation of sediments and the transformation of organic matter. This regularity, which recognizes no exceptions, directly indicates the migration of oil and gas from below, across the crystalline basement; that is, origin at depth.

The presence of great masses of hydrocarbons in the depths of the earth is confirmed by the huge columns of flame observed in certain volcanic eruptions, and by the appearance of mud volcanos - a manifestation in another form of the same subterranean forces that create flaming volcanos.

The depth of the roots of these mud volcanos is proved by their repeated violent eruptions, the great number of subsidiary volcanos, the nature of the mineralization in the waters discharged by them, and by the existence of transitional forms between mud and lava volcanos. The gas from mud volcanos, like the oil accompanying it, doubtless also comes from a great depth.

The origin of oil and gas at depth is testified to by their clear association in many regions with deep ruptures. This association is evident in Egypt, in Morocco, in the Vienna basin, in the Scandinavian peninsula, in Texas, Brazil, and Argentina. In the U. S. S. R., this appears very distinctly in Baikal, in Chelyabinsk and the grabens around it, and in other regions.

The association of oil with deep-seated ruptures is confirmed not only by excretions observed in certain regions that are connected with dikes and other intrusions of igneous rocks, but also by oil seeps on the surfaces of crystalline rocks observed in many countries and by the appearance of oil and gas in crystalline shields.

Besides deep ruptures, the gas and oil hydrocarbons in their movement to sedimentary rocks and to the earth's surface, make use of volcanic pipes and of certain plutons for example, the Siberian diamond- and iron-bearing pipes and the alkaline-syenite pluton in the Kola peninsula.

Direct proofs of the deep-seated origin of oil are the numerous exposures of oil from crystalline and metamorphic rocks which are known in many countries and are frequently seen far from any sedimentary deposits; exudations are known on both the Canadian and Scandinavian shields.

The origin of oil at depth is also supported by the lack of correspondence between the so-called oil-collecting areas and the actual quantity of oil concentrated in certain deposits. The clearest example of such lack of correspondence is in the deposit of bituminous sands on the Athabaska River in western Canada.

The formation of oil by inorganic synthesis can take place according to various schemes, some of which are used in industry. Most important are the reactions in the direct synthesis of hydrocarbons under high temperatures and great pressures. Evidently under the same conditions, hydrocarbons form from carbonic acid and water, or hydrocarbons and carbonic acid, and sometimes hydrogen sulfide (the Pincher Creek condensed gas deposit in Canada, containing 43 percent hydrogen sulfide) form concurrently.

The absence in petroleum gases of such components as nitrogen, hydrogen chloride, and carbon dioxide, which are so common in volcanic gases, is explained by the great chemical reactivity of the first two and the transformation of carbon dioxide into hydrocarbons and water or into carbonic acid.

The deep-seated origin of oil is a geologically proven fact. What remains to be studied is the

geochemical side of the problem. Further investigations should therefore be directed chiefly toward this aspect. Geologic investigations should aim at discovering new regularities in the distribution of oil in the earth's crust so that these may be used to practical ends.

Vassoyevich, N. B., CERTAIN ERRONEOUS CONCEPTIONS OF THE FORMATION OF OIL. The successes achieved in recent years in oil geology and geochemistry have set the problem of oil formation on the right path and made it possible to find answers to a number of important genetic questions of principle. In addition, both the presence and the causes of mistakes that have aided the rise of incorrect conceptions of the origin of oil have become clear.

According to the newest data, the formation of oil takes place in stages, of which the first is associated with the rise of rudimentary microoils and their subsequent alteration upward toward proper oil. The formation of microoils is widespread in nature, being a result of the process of sedimentation in the biosphere, and is determined by the inevitable rise of bitumens from the fossilization of any organic matter in any bodies of water, regardless of whether it is concentrated or disseminated in the sediments.

The formation of bitumens and of the microoils in their composition is an accessory process to the formation of carbonaceous matter (in the broadest sense of the word); and it is determined by the presence of lipoid and albuminous components in the organisms from which it originated, including those micro-organisms which cause the biochemical decomposition of organic matter in the initial stages of lithogenesis. The maturing of microoil and the increase in its content is connected with physico-chemical processes in the latest stages of lithogenesis. Both the general quantity of organic matter as a whole and of its components occur in very small amounts in sedimentary rocks.

The formation of oil (macrooil) is caused by a wide migration of microoils with the approach of definite thermodynamic conditions that vary for different types of rock and their combinations. For the clay sediments that are most widespread in the sedimentary lithosphere and usually the richest in microoils - if there are layers of sandstone or other collecting rocks in them - such conditions arise when the clay sediments are contained beneath rock strata more than 1,500 meters (m) thick, though the process of migration can also begin earlier.

Some of the originators of incorrect hypotheses on the genesis of oil have mistakenly assumed that gross transformation of organic matter into oil is possible. They ignore differences in the chemical structure of the different components, both of living matter (the source or organic matter in the pelosphere and the sedimentary lithosphere) and of the products of its fossilization. They also ignore the following: 1) the brief nature of these components; 2) differing variants of the hypothesis of gross transformation of organic matter into oil; 3) the false basis of this hypothesis in all its variations; 4) criticism of the correct variants of the theory of oil-producing rocks (the theory of microoils) from the position of the mistaken hypotheses of gross transformation of organic matter into oil, and the refutation of such criticism by arguments answering it.

The existence of erroneous conceptions of the organic origin of oil appears to be the basic reason for the attempts to resuscitate the nonbiogenic (mineral) hypotheses. There is a great similarity in the arguments by authors of such hypotheses against the organic theory, with arguments against the latter from the side of the authors of its mistaken variants. The futility of hypotheses of the inorganic origin of oil is evident. The formulators of these hypotheses are mistaken both in method and logic.

A series of tasks should be aimed at working out the problems of the formation of oil.

Balukhovsky, N. F., THE RELATIONSHIP OF THE ORGANIC MATTER OF COAL AND OIL IN THE DONETS BASIN. The accumulation of sediments in the Donets flexure took place under deltaic conditions. The Donets basin is related to basins of parallel type. Many peatbogs, during the middle Carboniferous, occupied a space of a few thousand square kilometers. Their characteristic peculiarity was a cyclical accumulation of sediments in cyclothems, along with predomiant subsidence. In the "Red Army" and "Lisichan" districts one finds sapropels as lenses above layers of carbon. When the role of marine sediments is increased, especially in zones of transition from the carbonate facies of the lower Carboniferous to the terrigenous facies, the amount of sapropel in the stratigraphic section is considerably greater.

In those regions of the Donets flexure where there is no appearance of regional metamorphism, the average bituminous character of the rocks and the specific gravity of the bitumens increases from the Moscow strata to the Visean and from the Tournasian to the Frasnian. In both complexes of sediments, a gradual transition from light fatty bitumens (above) to heavy asphaltic bitumens (below) can be traced. The amount of bitumen increases from 0.01 percent in the Moscow beds to 0.5 percent in the lower Visean. The heaviest resinous-asphaltic bitumens are concentrated in the oil-producing suite; the medium and light bitumens border it as an aureole and produce the heavy bitumens.

In the quarries around Razdolnoye (in the southern Donets basin) there have been observed

clear cases of the generation of oil from bituminous shales. The limestones of the Tournasian here include about 10 beds of brown bituminous shale. The bitumen migrated upward during the liquid phase from the bituminous shales and impregnated and stained the overlying limestone to a black or dark-gray color. Later, the bitumens were metamorphosed and now are represented by keratins. In the light of present-day chemistry of coal, the buried organic matter-humic or sapropelitic, homogeneous or disseminated-is represented by a hard colloid or coagulum.

In the general scheme of colloidal transformations of buried organic matter, one can distinguish three different processes in the congealing of the original mass: a) the formation of hydrophilic organic colloids (peat and brown coal); b) the formation of oleophilic organic colloids (sapropels, kerogen, and oil); and c) the formation of methanophilic organic colloids (coal).

The first two systems of colloids are characteristic of the brown-coal stages of development of organic matter; the third belongs to the solid-coal stage.

Fatty coals and kerogen have the property of being hydrophobic; this is what radically distinguishes sapropelitic organic matter from humic. In fatty coals, oil shales and bituminous shales acquire the properties of solvents, penetrate the intermicellular space, push apart and dissociate the micellae and gradually peptize the remaining mass.

If the organic gels in the bed containing the micellae have somewhat polymerized components exposed to hydration, the more mobile components that are formed systematically fill up the intermicellular liquid, increasing the pressure within the stratum. The embryonic oil is the intermicellular liquid of the oleophilic colloids. The granular mass remaining after the migration of the oil is very distinct from oil in composition; this circumstance is widely used by the opponents of the theory of oil-producing suites.

The solid-coal stage of organic matter is characterized by the increased removal of volatile constituents from the buried organic mass.

Electron-microscope investigations of solid coals, made by V. I. Kasatkin, have established that the organic matter in coal is a spongy mass, thoroughly penetrated by submicroscopic pores. The rise of these enclosed pores is a result of the separation of gas into bubbles in the chemical transformation of the organic matter of coal during metamorphism. The generation of trillions of cubic meters of methane in the coal beds produced in every coal basin is a fully established fact. The paragenesis of coal and methane and of oil and methane that has been observed everywhere supports the theory of oil-producing suites and at the same time serves as a very important fact to contradict the theory of the inorganic origin of oil.

According to calculations made by us, each ton of coal in the process of metamorphic change from long-flame [Ed. : soft?] coal to anthracite gives out about 40 m^3 of methane mixed with ethane and hydrogen. The great role of the gaseous phase in the process allows us to see, in the accumulations of methane, a dispersing medium for the humites during the solid-coal stage.

Experiments by T. A. Kukharenko show that D and G grade coals in hydrogenizing approach the volatile-fatty stage in their properties; grade PS, T, and A coals strive toward this same mean condition. Thence it follows that the metamorphism of coals, from the long-flame to the volatile-fatty stage, goes on under reducing conditions, while the alteration from K to A is produced in an acid hydrothermal environment. At the border of grades PZh and K there is an important thermogeochemical stage characterized by change from a reducing to an acid environment.

Conditions in the Donets basin allow the reconstruction of sections of eroded suites of the Paleozoic, and reproduction of the temperatures and pressures that existed at the end of the Hercynian in the formation of coals of various grades. With the most probable geothermal gradient being 40° per kilometer, according to calculations, we have the thermodynamic conditions expressed in table 1 [Ed. : Not reproduced in original Russian summary.].

The reducing environment in the coal series of the Donets basin is maintained up to temperatures of 160 to 170°. According to E. A. Fersman's data, water above $100^{\circ}C$ begins to act like a weak acid. Evidently at the beginning of the "inversion stage" of development of the Donets geosyncline there was intensive migration of hydrogen from the depths to the upper part of the sedimentary lithosphere.

The hydration of buried sapropelitic organic matter took place both under the influence of hydrogen at depth and through the biogenic hydrogen in waters containing H_2S.

According to averaged data, among the stages of carbonization of coal, the physical properties of rocks and the emplacement of gas and oil deposits, the relationships of which are expressed in table 2, have been noted [Ed. : Not reproduced in original Russian summary.].

The creation of gas and oil deposits has been more decisively influenced by a sharp decrease in the permeability and porosity of the rocks, corresponding to the gap between volatile coals and volatile-fatty coals.

Klimenko, V. A., SOME DATA ON THE ORIGIN

OF OIL IN THE DNIEPER-DONETS BASIN, AND ON THE CONDITIONS OF FORMATION AND DISTRIBUTION OF OIL DEPOSITS WITHIN IT. Deposits of oil in the Dnieper-Donets basin have been discovered in sediments of the Devonian, the lower and middle Carboniferous, and in Permian and Triassic sediments. They are lacking on the slope of the Ukrainian crystalline shield and the Voronezh crystalline massif.

The most intensive magmatic activity has been established in the region of Chernigov; however, a hole drilled through the center of the accumulated magmatic rocks which penetrates the entire sedimentary and extrusive series and uncovers the crystalline basement has not revealed even the slightest traces of oil.

Analysis of the sedimentary facies and study of the conditions of their accumulation in the depression has shown that in the central, most intensively subsiding part of the basin, in Upper Devonian, upper Visean, and Namurian times, conditions were favorable for the accumulation in sediments of a great quantity of organic remains, their rapid burial and their alteration into oil hydrocarbons (reducing medium, sulfide and hydrogen sulfide geochemical facies, the biochemical factor, and so forth).

Chemical and luminescence investigations of the types of clay rocks of the Devonian and Carboniferous (clay shales and clay marls) in the Dnieper-Donets basin has shown that these rocks contain a great quantity of disseminated oil hydrocarbons (0.5-1.5 percent and up to 5 percent) remaining in them after solidification and lithification. This indicates the considerable number of oil hydrocarbons exuded into porous strata in the process of solidification and lithification of these rocks.

All the facts indicated above allow us to presuppose an organic origin, and not a magmatic or any other inorganic origin for the oil in the depression.

The formation of oil and gas deposits in the Dnieper-Donets basin is closely associated with the structures of this basin and the conditions under which local structures of various types were formed. The formation of the structures in the depression and the formation of the oil deposits in it are closely interconnected processes.

The Dnieper-Donets basin is a platform structure, and hence is characterized by dislocations in the form of ruptures and faults; six of them are marked out in the basin. These appeared in the form of flexures in the Roman-Shebelin, the Isachka-Poltava, the Bakhmach-Balakla and the Khorol-Mikhaylov series of sedimentary rocks. In addition, broad anticlinal and dome structures are also characteristic of the basin.

Within the limits of the Dnieper-Donets basin the following tectonic elements are distinguished: a) the northeast and southwest flanks of the depression; b) the northeastern and southwestern zones of step-faults; and c) the central, most deeply subsiding part of the basin. All these elements differ both in their construction, in the thickness of the accumulated sediments, and their displacement. The central part of the depression subsided most intensely, the zones of step- faults less intensively, and the flanks of the basin very slowly.

Oil-producing rocks could be formed only in the central part of the basin, where organic matter accumulated and was rapidly buried as a result of the intensive downwarping of this portion of the basin, the rapid accumulation of sediments in it, and the presence of reducing conditions and favorable geochemical facies. On the flanks, an oxidizing environment predominated, and successive uplifts and erosion of the sediments could not help the formation of oil and gas. The subsidence of the oil-producing rocks to a considerable depth facilitated their solidification and aided the migration of oil and gas from the oil-producing into the reservoir rocks.

Salt tectonics played a significant role in the formation of local structures in the Dnieper-Donets basin. The salt, having begun to move at the end of the upper Carboniferous and the beginning of the Permian toward zones of lower pressure--ruptures--dislocated the flexure of the Roman-Shebelin, the Isachka-Poltava, and the Khorol-Mikhaylov series, creating along these flexures a whole group of structures more or less complicated by the salt. In some strata, it not only lifted the rocks within the arch by also ruptured them (the Roman, Isachka, Dmitriyevka, and Sinevka); in a second group, it merely uplifted the arch and ruptured the pericline (the Radchenka, Chernukhin, and Glinsko-Rozbyshev beds); in a third, it ruptured the flanks (the Dikan and Solokh strata); and in the fourth group, it merely elevated the arches, rupturing neither the flanks nor the pericline (the Sagaidak and Zachepilov).

As a result of the action of the mass of salt on the rocks overlying it, there was a stretching of the beds and also some rupturing with the formation of local faults. In the anticlinal structures the most extensive great faults are the northwestern and northeastern; in the domes they are radial and concentrated. Further movement of the salt led to the differential uplifting of individual blocks.

Parallel with the formation of local structures complicated by the salt, there was in the Dnieper-Donets basin, formation of oil and gas deposits. Salt, intruding into the sedimentary rocks along the flexures, formed a series of cupolas and broad anticlines with centers of salt within them. Oil and gas began to travel toward the tops of these structures and to form deposits in tectonic

and stratigraphic traps both on the flanks of the structures turned toward the central part of the depression and in the arches of the structures. With further formation in the arches of the uplifted blocks, complicated by the salt, the oil and gas, if they were not impeded (by impermeable rocks), traveled to the more uplifted blocks and formed deposits of oil and gas in them. The paths for this migration were both the porous rocks and the system of fissures formed as a result of salt tectonics.

Attempts at prospecting for oil and gas in the Dnieper-Donets basin have shown that the oil and gas migrated within it from the central part to the flanks. The zones of ruptures and step-faults--the Roman-Shebelin, the Isachka-Poltava, and the Khorol-Mikhaylov--and the flexures formed along them were the barriers which blocked the further movement of oil and gas toward the flanks of the depression and forced them to accumulate in lithologic, stratigraphic, and tectonic traps formed along these ruptures and flexures - especially in those places where the flexures were complicated by salt domes and stocks.

In the central parts of the depression at the first stage of migration, the deposits of oil and gas formed about the projections of the crystalline basement of the basin; during the formation of great salt structures of the Glinsko-Rozbyshev, Solokh-Dikan, and other types, the oil and gas could partially travel into the arches of these structures and form arched bedded deposits in the Carboniferous, Permian, and Triassic sediments. Gas, being the most mobile, could migrate also into the Jurassic sediments and form industrial-grade deposits there (in the Solokh and the Belsky structures).

Such were the conditions under which oil and gas deposits were formed in the Dnieper-Donets basin.

Snarsky, A. N., THE FORMATION OF OIL AND GAS DEPOSITS IN THE SOVIET PART OF THE CARPATHIAN FOOTHILLS. Along the front of the Carpathian arc there stretches a belt of Neogene formations making up the Carpathian foothill flexure. The flexure is subdivided into three zones: the folded Neogene, the Stebnik zone, and the zone of salt-bearing formations with "deep-seated" folds of the Borislav type.

The borders of the Carpathian foothill flexure are, to the southwest, the Soviet part of the eastern Carpathians and, to the northeast, the Volyno-Podolskaya end of the Russian platform. The Carpathians have been partially moved over the sediments of the foothill flexure.

The Carpathian foothill flexure is composed chiefly of rocks of the lower Neogene, mainly in the belt adjacent to the Carpathians; in the lower part of the section it is composed of Paleogene sediments. Mesozoic and Paleozoic sediments make up the substratum of the foothill flexure.

Lying between two extensive geologic regions--the Carpathians and the Russian platform--the foothill flexure reflects the features of its construction. It represents the zone of step-by-step subsidence of the edge of a geosyncline. Blocks of the platform were drawn into the subsidence and form the substructure of the Tertiary formations. Tectonic forces from the direction of the Carpathians caused a crumpling of the rocks lying in front of the Carpathians, which were being thrust toward the northeast, and the formation of a Stebnik advance covering a considerable part of the flexure.

By tectonic and stratigraphic criteria, the Carpathian foothill flexure is subdivided into two zones: the interior and exterior. The boundary between the zones is the plane of the Stebnik advance from its emergence on the earth's surface to the point where it is cut off by faults lowering the substratum of the interior zone to a considerable depth. The exterior zone is characterized by the development of middle and upper Miocene deposits lying unconformably upon Mesozoic and Paleozoic sediments.

The northeastern flank of the Carpathians is made up, basically of rocks of Paleogene and Cretaceous origin, primarily in flysch facies. The cross section of the interior zone, lying next to the Carpathians, represents a salt-bearing series (the Vorotyshchen series) and the Stebnik sediments (the Stebnik series).

The interior zone of the flexure is subdivided into two tectonic stages. The first is the continuation of the Carpathian folded strata. The lower and northeastern border of the first zone is the surface of the Stebnik advance. The southwestern border is not accurately determined, nor is it known, because the Miocene sediments extend far under the Carpathians. On the southeast, the Tertiary sediments are overlapped by the Pokutsk [Ed.: "inclined," "sloping"] Carpathians.

The sediments of the second tectonic stage, judging by seismic data, are characterized by gently sloping bedding. The northeast border of the exterior zone is a system of faults. The subsidence of the substratum was not uniform: this caused the differential thickness and facies of the Torton and Sarmat deposits.

Pressure from the direction of the Carpathians caused the formation of folds generally parallel to the Carpathians. Consideration needs to be given to the possibility that stratigraphic traps could be formed, enclosing structures and other forms favorable to the accumulation of oil and gas deposits.

In the Carpathian foothill flexure and the

adjacent part of the Carpathians, the intraformational waters are of two types: chlorine-calcic and hydrogen-carbonate-sodic. The chemical characteristics of these waters are associated with the history of their geologic development and correspond to the tectonic zones and the degree of uncovering of the structures.

Hydrologically, the Carpathian foothill flexure is a zone where the interchange of waters is hindered; this appears to be a factor favorable to the retention of oil and gas deposits.

Within the region under consideration most of the strata had a nearly hydrostatic initial pressure. In the portion of the Borislav folds that had been moved and in the Khodorovich folds, pressures were found that considerably exceeded hydrostatic pressure. The author submits a summary of data indicating that the coefficient of pressure increases, at 10 m of depth, reaches 1. 83.

After a brief survey of the chief suppositions on the origin of oil in the Carpathians, a description is given of the bituminous shales of the Menilitov series, which are taken by the author to be oil producers.

The Menilitov shale series is understood to mean a homogeneous thickness of rocks composed primarily of shales, but intermingled with sandstones, marls, and siltstones. Most of the shales are bituminous. The Menilitov series corresponds stratigraphically to the upper part of the foraminiferous beds of the northern Caucasus. In lithology and bitumen content, the Menilitov shales are similar to the Spassky shales of the Lower Cretaceous, which are marked by a greater degree of diagenetic alteration.

In considering objections of the partisans of homogeneous organic matter to the presence of oil-producing suites as the primary material in oil formation, one can bring forth proofs of the possibility of migration of oil from oil-producing suites to reservoirs, and the arguments against the possibility of accumulation of diffusely disseminated organic matter in significant amounts and its transformation into the range of hydrocarbons lack substantiation. Proofs of the formation of oil out of homogeneous organic matter and by inorganic synthesis are completely lacking.

One of the most essential objections to oil-producing suites is the difference in the amount of oxygen, sulfur, and bitumens in the Menilitov shales and in oil. The author maintains that the bitumen in the shales is a remnant having the same genesis as oil, but differing in composition and physical properites and incapable of migrating because of its physico-chemical properties.

The great extent of the Menilitov and Spassky shales, along with the geologic structure of the Carpathians and the Carpathian foothill flexure, permits an explanation of the permeation of Cretaceous and Tertiary reservoirs by oil.

The formation of the oil and gas deposits is represented as deriving from tectonic, stratigraphic, facies, and hydrogeologic peculiarities. The gas-bearing property of the exterior foothill zone is explained by its collecting and absorbing capacity along the path of the migration.

Some observations are made on the formation of oil and gas depoits in the Volyno-Podolskaya end of the Russian platform, which adjoins the Carpathian foothill flexure. The oil and gas in the Russian platform, which has a Precambrian substratum, can scarcely be explained by its upward travel, because this could take place only where there is a substratum of dislocated sedimentary rocks.

Formation of the Volga region's oil and gas deposits by migration from the Ural geosyncline must be considered improbable, because, in the light of V. A. Sokolov's calculations, the deposits already would have been destroyed in distant geologic time.

The oil and gas of the platform, which has a Precambrian basement and is made up of the sediments of an epicontinental sea, must be primarily associated with the adjoining zones of great development of Mesozoic and Cenozoic formations. In the Volga area, this zone is a depression, to which belongs the Caspian Sea and its adjacent districts.

For the Volyno-Podolskaya end of the Russian platform such a zone can be the Carpathian foothill flexure.

Potapov, I. I., GAS AND OIL FORMATION AND THE ACCUMULATION OF BITUMENS IN THE LITHOSPHERE. The organic origin and the migration of oil are fundamental basic positions which now determine not only the essential features, but also the full solution to the problem of the origin of oil deposits. The basic aim in the present discussion must be to free the theory of the organic origin of oil from its deficiencies and, as a result, arrive at the essential perfection of the theory.

The main unproved positions of the organic-migration theory that require radical revision are the following: a) the assertion that, as a result of biochemical and thermal transformation of organic sediments, there immediately arises an initial liquid-droplet, diffusely disseminated oil; b) that this liquid-droplet, diffusely disseminated oil, as a result of the solidification of the "oil-producing" suite under pressure of the overlying rocks, is exuded from the clays into porous, collecting rocks and migrates farther along the beds, also in the form of a liquid until it finally forms an oil deposit in an appropriate

"trap;" c) that the process of oil formation goes on in a reducing environment and requires a great number of ions of free oxygen; and d) that the change in the form of hydrocarbons in the earth's depths goes from asphalt to resinous oils, fatty oils, naphtha oils, paraffin oils, and hydrocarbon gases, which are the final product of the subterranean transformation of oil.

Microscopic and microbiologic observations and detailed investigations testify that the hydrocarbons arising through anaerobic decomposition of the remains of once-living matter do not consist of droplets and pellicles of liquid oil, but primarily of methane (CH_4 gas) which is a limited stage in the saturation of carbon by hydrogen, and also of the viscous and solid large-molecule hydrocarbons incapable of migration (usually $C_{15}H_{32}$ and higher).

This very "swamp gas," methane, is the most widely distributed hydrocarbon in nature, and always enters into the composition of oil and forms condensed and "dry" gas deposits; it is a product of anaerobic biochemical decomposition of organic remains, and must be taken as the basic rudimentary hydrocarbon capable of making a beginning in large-scale accumulation of various bitumens far from the place of its origin.

Special significance in estimating the migrating properties of diffusely disseminated liquid-droplet oil must be attributed to the so-called "hanging" deposits of oil, bordered by oil-water contacts, and inclined at angles of 30° or more. These deposits convincingly testify to the very difficult natural rising of liquid hydrocarbons in the "buried" intraformational waters of the collecting rocks.

The clearest and most obvious instances of migration are not those of liquid oil but of gas--about a thousand times lighter than oil--and water, which are quite close to each other in density. The mobility and great penetrability of hydrocarbon gas categorically testify to its inclusive role in the formation of accumulations of hydrocarbons and deposits of oil.

A reducing environment is characteristic only of "oil-producing" organic matter, in the full sense of the word, and, to a lesser degree, of mixed "producers," usually argillaceous suites, but is not at all characteristic of collecting rocks. The latter rocks--the only ones in which oil deposits are concentrated and the paths of their migration are found--have an oxidizing environment characterized by the absence of ions of free oxygen. The inevitable process of subsurface oxidation of the hydrocarbons under the influence of this medium is, in essence, also the process of oil formation which is being carried on to the present time.

The accumulation of bitumens in the lithosphere and especially in the collecting rocks formed by exogenic processes, where there are clear traces of a former oxidizing subaerial environment (sulfates in buried waters, the presence in terrigenous material of oxide minerals, the presence of free nitrogen, and other signs), testifies that the bitumens falling into this medium must be altered in the same direction as on the surface of the earth: from light oils to heavier ones, to asphalt and kir (oil-cemented sandstones). There is no sharp boundary between hydrocarbon gas and liquid oil. These are very similar substances, genetically closely connected in their various transitions and their dependence on conditions in the enclosing media. The gas originating in a reducing environment (argillaceous suites, some strongly carbonate rocks, and portions of beds where oxidizing was lost at the time of hydrocarbon migration) in the course of a long time does not change its form and, in accumulating, forms deposits in reservoir rocks of the most varied origin. In an oxidizing medium (most collecting rocks), the hydrocarbon gas inevitably changes form: it is oxidized, becomes heavier, is enriched in ever greater quantities of liquid hydrocarbons (condensation), and is gradually transformed into oil. This process is, generally speaking, reversible, but in an oxidizing environment in reservoir rocks, where bitumens are accumulating, it develops in the direction indicated--from gas to oil and farther to hard bitumens and asphalt--and not the reverse.

The problem of the formation of oil deposits can be quite accurately solved by a consideration of the "chemical" origin of the oil of this or that horizon or suite by studying the morphology of the deposits and the degree of alteration of the adjacent intraformational waters. It is most logical to consider the decrease in the solidity of the oils and the distribution in the same direction of considerably altered intraformational waters (sulfateless, alkaline) as the consequence of a primarily unidirectional migration of the gas from the nearby gas-producing basin and as the result of the continuity of this process in time. The deposits are concentrated usually on the flanks and pericline of the gas-producing basin.

The oil deposits were not formed from gas accumulations all at once, but during a rather long period of time. The enormous quantities of gas, equivalent to the present deposits of oil, were built up from many small, gradually inflowing streams and bubbles of gas, which were also gradually absorbed and dissolved into the initial clots of liquid oil. In the area of the gradually forming and solidifying deposit, a determining role was played by the transportation by the gas of pellicles and droplets of liquid oil. Where the necessary or sufficient geochemical and geophysical conditions were lacking there arose condensed deposits or deposits of dry gas.

In the crests of anticlines and in the tops of uparched and tectonically screened beds, that is,

in traps, there was scarcely any of the freer lateral migration. Here there was a striking predominance of vertical migration of gas and vapors, proceeding chiefly as slow diffusion. The formation of overlying deposits by the upward movement of oil through open fissures was of little importance.

The present condition of the various types of oil and gas, like the present condition of their deposits, is neither the end nor the beginning of their existence; it is only a contemporary stage in the uninterrupted alteration within the lithosphere.

The processes of oil and oil-deposit formation are proceeding within reservoir rocks uninterruptedly and differentially, but in a definite direction in association with the general course of geotectonic development of the lithosphere: periodically intensifying, dying down, ending, and renewing themselves under new conditions.

Shardanov, A. N., TYPES OF OIL AND GAS DEPOSITS OF THE KUBAN AND THE CONDITIONS OF THEIR FORMATION. The known oil and gas deposits of the Kuban are associated with the extensive Azov-Kuban oil- and gas-bearing basin. Within the basin are marked out various geotectonic units that have gone through different geotectonic histories. The northern past of the Azov-Kuban oil- and gas-bearing basin is related to the area of the young epi-Hercynian (Scythian) platform, where complexly folded Paleozoic sediments underlie a blanket of Mesozoic and Cenozoic deposits. The central part of the basin is occupied by the frontal (Alpine) Indolo-Kuban flexure which, within the area of Krasnodar, is divided into three parts: the western (or Azov), the central (or western Kuban), and the eastern (or eastern Kuban). South of the frontal flexure extends the mountainous structure of the Greater Caucasus, whose western terminus is carried away into the subsidence of the superimposed Kerchen-Taman cross fold.

The oil and gas deposits are connected with the sedimentary rocks of the Alpine geotectonic cycle. In the Triassic, the marine basin with terrigenous-carbonate sedimentation was set off by the zone of the Greater Caucasus; the Scythian platform region was dry. In the Lower and Middle Jurassic the Greater Caucasus geosyncline was filled with a thick series of sand-clay sediments. In Upper Jurassic times, carbonate deposits were formed west of the Belaya river basin and, west of it, terrigenous-carbonate deposits. In the Lower Cretaceous through the Aptian, the accumulation of sediments was limited by the structures of the Greater Caucasus and the zone of contemporary frontal flexures, and the entire area of the Scythian platform from the Albian was drawn into the flexure. The sedimentation of the Lower Cretaceous was chiefly sand-clay; west of the Belaya river basin (that is, to the west of the Adygeyskaya transverse uplift) the thicknesses of sediments greatly exceed those of the eastern regions. In the Upper Cretaceous, sedimentary accumulation was continued both in the geosynclinal zone and on the platform. Starting in the Paleogene, the central zone of the Greater Caucasus was uplifted; to the north a narrow flysch flexure was developed, while sand-clay sediments were accumulating in the Caucasus foothills. In the Eocene, the geotectonic situation did not change. From the Oligocene on, there was a great uplifting of the Greater Caucasus and the Caucasus foothill flexure was folded. During the Miocene and Pliocene, in the frontal foothill flexure, there was an accumulation of thick sand-clay series of strata.

The very greatest reserves of oil and gas on the dry land are connected with the zone of the western Kuban flexure, where maximum thicknesses of unmetamorphosed, weakly dislocated sedimentary series of the Mesozoic and Cenozoic have been noted. In the zone of this flexure, two oil-bearing subbasins are distinguished: the Slavyansk-Ryazan and the Adagum-Afips, associated with basins having the same names; they are separated by the Kurchan-Mingrel uplift.

Most of the differing types of deposits are associated with the southern margin of the western Kuban flexure. Here are intraformational deposits connected with lithologic traps in the Maikop, Miocene, and Pliocene, with lithologic-stratigraphic traps in the Eocene, Oligocene, Miocene, and Pliocene, and with tectonically screened traps in the Paleogene. Here are also deposits of the massive type, associated with dolomitized limestone and also with littoral facies in a zone of flexure of several horizons of the Miocene.

With the Kurchan-Mingrel uplift--the central anticlinal zone of the western Kuban flexure--are associated intraformational deposits in structural and lithologic traps of the Miocene. Along the northern margin of the western Kuban flexure are developed intraformational deposits of gas, associated with lithologic traps of the Miocene.

On the Adygeyskaya uplift are known intraformational deposits connected with lithologic-stratigraphic traps of the Jurassic and with structural traps in the Lower Cretaceous.

In the Scythian platform zone, intraformational deposits of gas are developed in structural traps of the Bazal horizon of the Albian, and also in structural traps of the Eocene and Paleogene.

The oil and gas deposits in the Kuban are associated chiefly with those suites in which there was formation of oil. The rocks of the Lower and Middle Jurassic, the Lower Cretaceous, the Paleogene, Eocene, Oligocene, Miocene, and Pliocene are oil producing. The formation of deposits in most cases went on by lateral migra-

tion from the depression towards the uplift area, which are the zones of oil and gas accumulation. The formation of the deposits was a longlasting process, consisting of a number of phases closely connected with the region's geologic history.

The basic, motivating factor determining the primary migration of the hydrocarbons from the producing rocks of the oil- and gas-bearing basins into traps was the process of sedimentary solidification of the deposits. The hydrocarbons exuded into less solidified strata which retained their permeability, then migrated along them from regions of greater to zones of lesser pressure, where the fluids were differentiated by their specific gravity.

Regional migration of the liquid hydrocarbons from a given suite began only after the accumulation above of sediments at least 400-600 m thick. When the load and corresponding pressure ceased to increase, the migration could be interrupted, but it was renewed again when the pressure was increased.

The composition of the oils in the various deposits depends chiefly on conditions in the medium where gas and oil accumulate, that is, on conditions existing in the traps. The average initial composition of the hydrocarbons at the beginning of their migration was evidently fairly uniform, and in any case could not explain the variety in the compositions of the oils in deposits.

Zhabrev, I. P., THE GEOLOGIC HISTORY OF THE WESTERN KUBAN FRONTAL FLEXURE IN CONNECTION WITH THE CONDITIONS OF ACCUMULATION AND TRANSFORMATION OF ORGANIC MATTER. The development of the Greater Caucasus geosyncline in the Alpine cycle led to the formation of frontal flexures along the northern margin of this geosyncline in the Oligocene-Neogene. In this stage of development there was a complete reversal of the tectonic regime. The central part of the Greater Caucasus began to be intensely uplifted. The northern part of the geosyncline, on the other hand, subsided; this subsidence now enveloped also the parts of the platform lying next to the geosyncline.

Such a typical frontal flexure is, in the northwestern Caucasus foothills, western Kuban, where the general subsidence of the sedimentary complex in the central parts of the flexure after the Alpine cycle reached 8 km, of which more than 4 km was on the sediments of the frontal flexure (Oligocene-Anthropogene). The northern part of the frontal flexure was deposited on the epi-Hercynian Scythian platform. This limb of the flexure is characterized in its northern part by a gentle downward slope of the rocks toward the south, toward the center of the flexure. The southern part of the flexure, laid down on the Paleocene-Eocene flysch geosyncline, is distinguished by considerable steepness as a result of rapid accumulation of thicknesses of Oligocene-Neogene sediments toward the north.

In the present structure of the western Kuban flexure are distinguished: a) the southern margin of the flexure, where there is a development of diapir anticlines in the Oligocene-Neogene structural stage; b) the Adagum-Afips depression, with gently sloping anticlines and structural terraces developed in the same stage; c) the Kurchan-Mingrel uplift zone, where diapir folds in the west, crossing embryonic diapirs, merge into the gently sloping anticlines and structural terraces in the east; d) the Slavyansk depression of gentle anticlines and structural terraces; e) the platform flank, little known at the present time. The presence of gently sloping anticlines and structural terraces is suggested.

All the enumerated structural elements except the last contain oil and gas in industrial amounts. Extraction of oil and gas is carried on from the sediments of the upper structural stage, beginning with the Oligocene and ending with the lower Pliocene. In middle and upper Pliocene rocks along the southern margin of the flexure, in intensely folded areas, local appearances of oil and gas have been observed that are clearly associated with fluids which migrated from Miocene horizons.

The complex of sediments of the upper structural stage is composed chiefly of clay rocks alternating with sand and silt. Interbedded carbonate rocks are rarer. Clastic material entered both from the Caucasus land area and from the Russian platform in the north; it is characterized by wide distribution of quartz, sand and siltstones with disthene and staurolite.

Investigations of the disseminated organic content of the Oligocene and Neogene rocks have shown that both in quality and in amount, it is identical to the deposits of other regions generally held to be oil producing. The accumulation of like sediments continues at the present time in the western part of the flexure (cf. V. V. Veber's works). Already in the first stage of sedimentary formation there is an accumulation in the silts of hydrocarbons, whose quantity increases with the increase in sediments, both through new formation and continued emergence out of the solidifying clay-silts. The hydrocarbons are disseminated in the water both as colloidal particles and merging into true solutions. At the present time such a condition is found in the upper 500 to 600 m of the section, corresponding to sediments of the Anthropogene-upper Pliocene and, in part, middle Pliocene. The lower Pliocene Pontic sediments (with a depth of 1,500 m) already contain industrial accumulations of gas, but only in the most sharply pronounced traps. Consequently, the process of accumulation has already begun here, but thus far only of gaseous fluids. The succeeding Meotis-Sarmat interval in the section (1,500 to 2,500 m) contains indus-

trial deposits of both oil and gas. The middle Miocene-Oligocene sediments (2, 500 to 4, 000 m) are also gas and oil bearing. In the transformation of the organic matter of the latter the essential role may have been played by temperature (100 to 150°) and pressure (250 to 400 atmospheres).

Such conditions will favor solution of liquid hydrocarbon particles in gas-forming media, thus facilitating vertical migration. Similar vertical migration is also possible from the oldest sediments of the lower structural stage. In the movement of the waters filling the collecting rocks, resulting from separation by specific gravity, there is an accumulation first at the top of the stream and then in favorable traps, of the various components forming the oil of both syngenetic and epigenetic sediments, and migrating upward from below.

The western Kuban frontal flexure must be considered a single oil-bearing basin both in area and section. The intensive subsidence (up to 4 km) in a fairly short interval of time under shallow-water basin conditions, widespread development of island chains, shoals, lagoons, and consequently of sediments comparatively enriched in syngenetic organic materials, the considerable loading of the lower complex, and a part of the organic matter rendered, as a result of increased temperatures and pressures, into gas-forming fluids migrating upward--all these have created conditions favorable to the possible accumulation of oil and gas throughout the whole section of the frontal flexure. In sediments where the collecting rocks were extensive in area (the Maikop, Meotis, and possibly Sarmat), these possibilities were turned into realities.

Babayev, A. G., CERTAIN PECULIARITIES OF THE FORMATION OF OIL AND GAS DEPOSITS IN THE MESOZOIC SEDIMENTS OF WESTERN UZBEKISTAN. At the present time it has been quite obviously shown that western Uzbekistan is an extensive, and potential oil- and gas-bearing province.

Geologically, western Uzbekistan is part of a very extensive epi-Hercynian platform. Within this region one can trace, very distinctly and almost ubiquitously, a division between the folded basement and the sedimentary mantle. In the region under consideration there are clearly localized foci of subsidence and uplift, which are to a certain degree inherited formations. Similar newly formed structures are, as is well known, peculiar to all other platforms as well.

The areas of subsidence in the western Uzbekistan oil- and gas-bearing province are rather large and gently sloping depressions like syneclises. The author considers them to be basins of oil and gas accumulation. The accumulation of sediments in these depressions took place against a background of slow and constant downfoldings which were made up, in places, of structures contemporaneous with the sedimentation, In the Mesozoic, these depressions were filled with shallow-water seas and at times with lagoons and lakes. Within this depression one can observe a distinct zonality in the facies; from this distinction emerges a genetic association of bitumens with definite types of facies. In these depressions there was not only accumulation of the original organic matter and its transformation into oil and gas, but also subsequent migration all the way to the final gathering in traps. Factual material testifies that all the occurrences of oil and gas deposits are also associated with these depressions.

The basic geologic premise of oil and gas formation in depressions of the western Uzbekistan platform area is long-continued, uninterrupted accumulation and diastophism of sediments. This concept, applied to other platform regions, is underscored in works by Link, Van Teip, Parker and Skitters, Hein, and Howard. The peculiar geologic structure of platfrom regions and, in particular, clear localization of depressions is just one of the fundamental factors determining the formation of oil and gas deposits on platforms. The importance of the structural factor in the oil- and gas-bearing province of western Uzbekistan has been quite definitely observed. In the western Uzbekistan depressions, sediments in the Mesozoic accumulated on structurally differentiated surfaces. Therefore the structural factor in the formation of oil and gas deposits began to appear in the earliest stages of oil and gas formation.

Disjunctive ruptures were important in the formation of deposits here; indeed they played a clearly supporting role. Their role was limited by the succeeding transformation of earlier formed deposits and particularly by the breaking up of single intraformational deposits into several tectonically screened or intraformational deposits. The presence of deep penetrating rifts having, it was thought, decisive importance in the formation of deposits for the platform regions of western Uzbekistan is not confirmed by factual material. It can be stated that in the platform regions deep ruptures are chance peculiarities and not the rule. The possibility of vertical migration of the hydrocarbon fluids under western Uzbekistan conditions is limited also by the small thickness of the sedimentary mantle. All this compels us to think that, in the process of oil and gas formation on platforms, ruptures were not of decisive importance as paths for the vertical migration of oil. No less important is the circumstance that in platform regions, as V. P. Savchenko has shown, the upper horizons contain water under greater pressure than the lower. Such a relationship of pressures not only prevents vertical migration of hydrocarbons but could even cause their migration downward from above.

Data on western Uzbekistan show that one can distinguish three oil-producing suites in the cross section of the sedimentary cover: 1) the Upper Jurassic, 2) the Albian, and 3) the lower Turonian. An interesting detail is observed in the relationship of the oil- and gas-containing areas of these series. It appears that the areal extent of oil and gas in the Albian sediments far exceeds those of the Jurassic and the lower Turonian. All this makes it improbable that, as V. B. Porfirev says, all the gas and oil occurences in the Mesozoic and Cenozoic sediments appeared as a result of migration of hydrocarbons from the Jurassic deposits. There is also no confirmation of O. S. Vyalov's assertion that the oil occurrences in the Mesozoic rocks came from migration along the surface of a stratigraphic unconformity from Paleozoic sediments. Huge accumulations of gas and oil are associated with the oil-producing suites in the Mesozoic section of western Uzbekistan, but even in places where there is no gas or oil these sediments are almost always enriched in disseminated bitumens. In the remaining parts of the Mesozoic section, as one would expect, disseminated bitumens are not found.

Aside from the oil-producing suites, oil and gas deposits are also concentrated in the Valanzhin-Aptian sediments, which are formations essentially different in character from the Upper Jurassic, Albian, and lower Turonian. If the oil-producing suites we have singled out are in all cases undoubted marine formations, the Valanzhin-Aptian strata are no less definitely subaqueous continental formations. The occurrences of gas and oil in them are secondary; they evidently came about through the migration of hydrocarbons downward from above (from the Albian beds). Suppositions that the hydrocarbons penetrated the Valanzhin-Aptian strata from the Upper Jurassic sediments are less realistic. This formulation of the question arises from the fact that above the oil-producing and oil-bearing Upper Jurassic sediments lies the thick salt and gypsum-bearing Kimeridge-Titon series. This series acted primarily as a screen, preventing the migration of hydrocarbons upward. The suggestion of possible migration of the hydrocarbons from the Albian to the underlying ones derives from two observations: 1) according to V. P. Savchenko's opinion, this could have been facilitated by the higher pressure of the water-bearing horizons in the overlying strata, and 2) in the solidification of the Albian oil-producing shales, the oil and gas could have been absorbed by the highly porous Valanzhin-Aptian terrigenous formations. One must also take into account the fact that over the Albian are situated the no less porous horizons of the Senoman clastic rocks. But in these, not only no industrial accumulations of gas and oil exist, but neither do disseminated bitumens. It is very possible that the Senoman beds were saturated with water under pressure which squeezed the oil out of the oil-producing suite into the porous layers beneath. All this allows us to think that a part of the hydrocarbons, migrating during the rise of the oil-producing suites, accumulated in tectonic and lithologic traps, while another was pressed out into the mixed rocks below where it gave rise to secondary deposits. At the present time there is much data on the possibility of hydrocarbon migration downward from above.

From what has been set forth one can see the great importance of lateral migration in the formation of oil and gas deposits on platforms. Deposits can also be formed, in principle, by means of ascending vertical migration, but from the example of the western Kuban deposits it is quite apparent that lateral migration is of primary importance.

Laliyev, A. G., PROBABLE OIL-BEARING SERIES IN A SECTION OF THE CRETACEOUS DEPOSITS OF THE KOLKHIDA LOWLAND. The low-lying part of Kolkhida, with a general area of more than 2, 500 square km, is sharply distinguished as an extensive isolated geomorphologic element of not only western Georgia but of the landforms of the whole Trans-Caucasus. It is covered by a thick mantle of Quaternary formations, and in its overall slope from east to west sinks below the level of the Black Sea. On the north and on the south respectively, it is bordered by the Greater and Lesser Caucasus mountain systems, and on the east by the meridian lying somewhat to the east of Kutais.

The stratigraphy of the Cretaceous deposits in the central lowland, based on drilling records and geophysical investigations, is as follows:

1. The Valanzhin-Goteriv: an alternation of thinly and thickly bedded gray limestones and dolomites, crypto- and microcrystalline structures with interbedded white gypsum more than 3 to 5 m thick, gray and dark-gray sandy-lime which is soft and sometimes viscous, clays and fine-grained strongly-clay sandstones to a thickness of 8 to 12 m. . . . . . . more than 500 m

2. The Barremian: limestones massively bedded crystalline structures, locally dolomitized; a few dolomites, partly porous structures and with a few interbedded gray and dark-gray limy and sandy clays up to 8 m thick. In some layers of the limestones particles of granite and quartz and pebbles of sandstones and tuffaceous rocks are included . . . . 700-800 m

3. The Aptian: limestones, gray and gray-green, glauconitic, with pelitic and crystalline structures and in the lower part with interbedded gray limy-sandy clays. . . . . . 100-120 m

4. The Albian: gray and dark-gray sandy-lime shales enriched with tuffaceous material, tuffaceous sandstones, pelitic limestones, pelites and crystalline tufas, plagioclase porphyries. . . . . 450-500 m

5. The Senoman: gray and green-gray limy, tuffaceous solid argillites, tufas, sandstones, and porphyries . . . . 40-60 m

6. The Turonian and the Senonian: primarily bedded limestones, gray and light gray, pelitic, sometimes with cryptocrystalline structures. In the Turonian, some layers and pieces of limestone have a pink color. In the southwestern part of the lowland in the Upper Cretaceous section, sandstones and limy-sand clays are interbedded . . . . 250-350 m

7. Dacian: greenish-gray and gray clayey limestones and marls . . . . 20-30 m

The sediments under consideration from the Cretaceous system and mixed areas to the north (Akiba, Mingreliya, Abkhaziya, and the regions of the lower Racha and Lechkhum) are, in their thickness, lithofacies, and conditions of sedimentation, sharply distinguished from the equivalent geosynclinal sediments (flysch zone) of the southern slope of the Greater Caucasus.

At the same time these sediments, though having considerable similarity to platform sediments, cannot, considering all lithofacies indicators, specific tectonic features, and the geotectonic history of the regions, be taken as fully identical to platform formations. Regarding the inclusion of the Kolkhida lowland and the adjoining regions to the north in the category of geotectonic structures distinguished by the designation "platformoid," the Cretaceous sediments of the regions described must naturally also be distinguished as a separate formation: the "platformoid."

Following the theory of the organic origin of oil and gas, in the Cretaceous section of the Kolkhida lowland deposits, we consider the chief oil-producing rocks to be the limy-sand clays and strongly argillaceous fine-grained sandstones of the Aptian, Barremian, Goteriv, and Valanzhin series, which are above all not solid or even viscous, and little different from contemporary marine silts.

The first indications of oil were met in the rocks brought up by the core drill from drill hole 8 (Kvalona) from a depth of 2, 713-2, 720 m (lower Aptian-upper Barremian); these rocks gave out a strong odor of oil, and in the benzine and benzol extraction they strongly stained the solvents. Subsequently, similar rocks (with the same strong odor of oil) were brought up from various levels of the Barremian and Goteriv-Valanzhin series in drill holes 15, 17, 18, 19, 21, and in other prospecting areas of Kvalona.

Proceeding from the conditions for formation of carbonate rocks (at times in lagoonal stagnant-water conditions), we come to the conclusion that periodically there were conditions favorable to the accumulation of carbonate oil-producing rocks, primarily in the Aptian and Neocomian, and secondarily in the Upper Cretaceous, in the Kolkhida lowland. In these favorable conditions, a role may have been played by the oil-producing, dark-gray, strongly organic pelitic formations of the Albian series.

The large favorable structures, cavernous and jointed collecting rocks, the first indications of oil from the upper Cretaceous in Chaladidi, the numerous appearances of oil and gas in exploratory holes in the process of drilling and testing in various levels of the Upper and Lower Cretaceous in Chaladidi, Kulevi, and Kvalona, and the calcium chloride and magnesium chloride waters allow us to evaluate the Kolkhida lowland as a prospective area for industrial accumulations of oil and gas in Cretaceous sediments.

Regional paleogeographic reconstructions along different horizons of the Cretaceous system testify that favorable conditions for the accumulation of oil-producing series in Cretaceous times existed repeatedly, not only in the Kolkhida lowland, but also in the neighboring regions of the Lesser and Greater Caucasus. In addition to these direct and indirect indications of oil and gas which were associated with the various horizons of the Cretaceous system in Abkhaziya, Mingreliya, Akiba, Racha, Kakhetiya, and within the Adzharo-Trialet system (some of which are evidently genetically connected with the corresponding series of the Cretaceous system), we must undertake extensive investigations to solve decisively the questions of oil production in the Cretaceous deposits of Georgia.

Mekhtiyev, Sh. F., THE OIL-PRODUCING SUITES OF AZERBAIDZHAN. The question of oil-producing suites is the basis of the problem of oil formation and the formation of oil deposits. There are not reliable data for distinguishing oil-producing suites in the section of the Paleozoic sediments of Azerbaidzhan. Most probably there were no conditions in the Paleozoic favoralbe to the formation of oil in the depths of Azerbaidzhan.

The geochemical circumstances of sediment accumulation, the geotectonic conditions of the basins of sedimentation, and the distribution of organic components in the rocks of the Mesozoic complex, along with a calculation of the oil and gas occurrences associated with these deposits, provide a basis for identification of the oil-producing suites in the Middle Jurassic sediments, in the Goteriv and Barremian, in the lower and middle Albian and locally in the lower Turonian strata.

In the cross section of the Tertiary system, the oil-producing character of the Maikop and Diatom suites and the presence of upper Eocene and perhaps lower Paleocene oil-producing deposits is confirmed by reliable data.

The distribution of bitumens, organic carbon, and humic acids in the rocks of the producing series allows us to acknowledge the possible oil-producing character of the Kirmakin suite in the lower section of the series.

The oil-producing suites that have been distinguished in Azerbaidzhan, and their distribution in the section, are in principle no different from the distribution of oil-producing suites in sections of the Mesozoic and Cenozoic series of a number of other oil-bearing regions in the Alpine geosynclinal belt of the southern U. S. S. R. (western Turkmenia, the Fergana valley, and the southern Tadzhik depression).

Further grounding and more accurate definition in the distinction of oil-producing suites require increased experimental work in the discovery of new, detailed qualitative characteristics of oil-producing suites and the application of the latest successes of modern investigative methods.

Sultanov, B. I., THE CAUSES OF INVERSION IN THE ALTERATION OF THE PROPERTIES OF OIL IN PRODUCING SERIES. The properties of oils, in association with the origin of geologic formations, in the majority of the world's deposits are altered in accordance with definite laws and trends. As a result of these alterations with stratigraphic depth a disproportionation of hydrogen and a loss of heterogeneous elements in oils occur. In the oils of Apsheron these alterations have an inverse character and take place in a manner contrary to the laws and without clear stratigraphic connections.

Within each deposit there has been noted a horizontal geochemical zonality of a hypergenic and catagenic character. Each zone is located in a different part of the structure and has a regional distribution. Within each zone are grouped oils and waters distinguished by properties characteristic of these zones. In zones of one character the composition of the oil and water is identical, regardless of their stratigraphic situation. The transition between the zone of a deposit (the horizontal zonality) is usually gradual, but sometimes within a single zone one notes vestiges of another zone in the form of blotches. Such a mosaic of geochemical conditions runs the gamut of the oil and water types that are distinguished by individual nuances.

Comparative study of the composition of oils and waters shows their close interdependence. The anomalous alteration in the composition of oil and water in the section is determined by the history of the region's hydrogeologic development. Infiltrating waters that penetrated into the sediments of the producing series on the one hand reversed the hydrochemical profile, changing formerly catagenic surroundings into hypergenic, and on the other hand mixed, and in places destroyed, the oil deposits.

The disposition and the influence of the hypergenic processes arose from the bottom of the producing series; this created an illusion of regular alteration in the qualitiy of the oils, as if they had been fractionated in their vertical migration across the series of rocks.

Interpretation of geochemical and geotectonic data shows the secondary character of alterations in the composition of oil and water, and the primary nature of the oil deposits in the upper and lower parts of the producing series.

Besides the geochemical factor in the alteration of the composition of the oil in the producing series, the influence of others has been noted--temperature, pressure, and so forth, under whose action some types of oil are altered during the subsidence of the collecting rocks.

Gorin, V. A., THE CHIEF GENETIC ZONES OF REGIONAL OIL AND GAS PRODUCTION IN THE SOUTHERN CASPIAN BASIN AND THE FORMATION OF DEPOSITS OF OIL AND GAS. (WESTERN MARGIN OF THE BASIN). The formation of oil and gas deposits in every oil-bearing province is closely associated with the history of its development and can be explained only on the basis of this interdependence.

In the structure of the southern Caspian depression one can distinguish its southeastern or most deeply subsided part and its borders: the Kurin and Trans-Caspian. Last of all two structural elements, tectonic stages, deserve attention: the Azerbaidzhan and Turkmen, which are associated with the Caucasus and Kopet-Dag regions of folding and subsidence.

The formation of these stages was determined by the subsidence of the basin and the formation of deep faults along its margins; this was clearly set off by periodic and regular intensive activity of mud volcanos in both Tertiary and present times. Analysis of the material and appearances of volcanism in the last half century is quite fully indicated in this regard.

Following the trend of the fault zones and the location of powerful, now active mud volcanos along these zones on the western margin of the southern Caspian depression, four genetic oil-bearing zones, four tectonic swells, are distinguished: along the northwestern margin, the northern Apsheron swell and the southern Apsheron swell, which together make up the "Greater Apsheron" region; and, along the southwestern margin, the Alyat swell and the Prikurin swell.

These four deep-seated regional tectonic swells (of the lower structural stage) fringe the margin of the Azerbaidzhan tectonic stage and form the basic zones of oil and gas saturation in

the whole section of Tertiary and Mesozoic sediments. All four swells meet at the northwestern corner of the western margin of the southern Caspian depression (the Pirsagat tectonic center).

The intermittent and continuous appearance of mud volcanism along the fault zones and the concentration here of very rich oil and gas deposits, which as a whole form belts of regional accumulation of oil and gas, testifies to the role of these faults as paths of oil and gas migration and at the same time to the many phases in the formation of these very deposits in the whole complex of sediments of the southern Caspian depression.

Inasmuch as the roots of mud volcanism lie at the bottom of the Mesozoic (Lower Cretaceous, Jurassic), and the mud volcanos themselves are determined by ruptures in the Tertiary and Mesozoic series, the same factor also determines the location of oil and gas formation in the southern Caspian depression. The centers of oil and gas formation lie in the sole sheet [Tr. :?] zone of the basin's sedimentary complex.

This situation compels us to consider the term "oil-matrix suite" as a conditional one, and to apply it only to those sediments which at some geologic period had subsided to a depth corresponding hypsometrically to that of the roots of present-day mud volcanism or to the region of the oil-producing zone. There are no oil-matrix suites. The term "oil-producing" would perhaps be more suitable.

The great oil and gas reservoir--the producing series of Azerbaidzhan--like the redbeds of Turkmenia, is not "oil-producing" and much less "oil-matrix" in the usual sense, but serves only as a receptacle for oil and gas migrating from the underlying series in the vapor phase, mainly through ruptures in the beds, over a period no less than the course of two phases.

Saturation through the fissures takes place in the initial stage of faulting; that is, when the beds are gently sloping. This determines the broad limits of their saturation with oil and gas in this phase.

Closely interdependent with the phases of migration and coinciding with the tectonic development of structures (traps) is the distribution, and later redistribution, of oil and gas in the many-layered deposits of the western and the eastern margins of the southern Caspian basin. Lateral migration within the beds takes place only in association with this, being limited by the area of oil saturation in the first phase of migration.

The lack of coincidence in plan of the deposits of the lower and upper parts of the producing series which are associated with the arches of folds corresponding to structural stages (with the formation of the so-called "hanging" deposits), confirms the many-phased nature both of the formation of the folded structures and of the migration of oil and gas in them, and is determined by the distribution of the fluids (oil and gas) already in the final phase of migration.

The character of an oil and gas deposit in the beds of the producing series (considering the qualitative character of oil and the usual deposition of lighter oil along faults) indicates the producing role of synchronic faults in the initial stage of migration of a given phase, and to the screening role in the final stage of the formation of folded structures and their deposits.

Thus, in general, lateral migration within beds takes place only within the limits of the zone bearing oil and gas and determines the subsequent distribution and redistribution by gravity of oil and gas in traps.

There are especially good prospects for oil in the flanks of the uplift that, during the period of migration of the oil and gas, were inclined toward the large adjoining syncline. Consequently, the present form of the uplift (and hence a structural map of any one stratum) still cannot be a criterion for selecting the direction of prospecting operations without a thorough analysis of the history of the entire province.

The prospects for oil and gas and the direction taken in searching for new oil and gas deposits in the southern Caspian basin are determined by the situation in area and section of the sediments in the above-mentioned genetic zones. This includes, in our case, the distribution of faults, mud volcanos, the various types of structures (traps), and, in particular, diapir folds, more and more of which are coming to light as exploratory drilling increases in the search for new oil and gas deposits.

Agabekov, M. G., THE DISTRIBUTION OF OIL DEPOSITS WITHIN STRUCTURES IN SEDIMENTS OF THE UPPER PART OF THE PRODUCING SERIES OF AZERBAIDZHAN. Scrupulous investigation of the oil deposits of exploited areas of the Apsheron peninsula, the Prikurin lowland, and other regions has shown that the latter are not strictly associated with the crests of corresponding anticlinal folds and that the contours of the oil deposits do not coincide with structural lines, but deviate in various directions from the arches of the folds.

Investigation has also shown that the deviations in these oil deposits gravitate only toward the adjacent depth of the synclinal flexure in the corresponding structure.

The regularity that has been discovered in the distribution of oil deposits in relation to

structural uplifts is of great practical importance in searching for oil and gas deposits.

Structural maps aid in understanding the regularities in the distribution of oil deposits on corresponding structural uplifts in the oil-bearing region. The distribution of oil deposits in those portions of the structural uplifts that are inclined away toward the troughs of adjoining synclines testifies to the lateral migration of oil and gas and against the migration of oil and gas is a vertical direction.

Deviation of the oil and gas deposits of the upper part of the producing series from the oil and gas deposits of the lower part is observed in cases where a projection of the structural uplift in the lower part does not coincide with the structure of the upper part.

Ismailov, K. A., THE DISTRIBUTION OF OIL AND THE CORRELATION OF CONTOURS OF DEPOSITS IN CONNECTION WITH LITHOLOGY OF THE RESERVOIR ROCKS IN THE DEPOSITS OF THE APSHERON PENINSULA. We have attempted to establish a connection between the lithologic composition of various horizons of the producing series and the quantity of oil distributed in them in various deposits of the Apsheron peninsula. For this purpose we have assumed the possibility of a genetic association of oil with the rocks that contain it, that is, with the producing series itself.

Our detailed investigations have established various relationships among the contours of a number of deposits in the Apsheron peninsula. Cases of both decrease and increase in the contours with stratigraphic depth have been observed. The contours of deposits do not depend on porosity or even on the relationship of clays and sands in the oil-bearing horizons.

The impossibility of the formation of oil and gas in the producing rocks themselves was expressed only in inferred conclusions; in the light of the newest geologic and geochemical investigations, the theory has no foundation. Almost all geologists are agreed that accumulation of organic matter and the formation of oil to one degree or another have gone on in all geologic periods and are continuing at the present time. The exclusion of these processes from the producing series is not convincing, since primary, oil-bearing rocks can be found among the most varied lithologic complexes, from normal marine to continental sediments inclusive. The same investigations, by Sh. F. Mekhtiyev, established the fact that in its content of organic matter (which, it is well known, is fundamental in the theory of oil-producing suites) the producing series is not inferior to a number of other stratigraphic units in the Tertiary complex of Azerbaidzhan.

The accumulation of organic matter and the formation of oil in terrigenous formations took place in both silty and sandy sediments. In the further solidification of the sediments under the weight of overlying series a considerable part of the fluid, including oil, situated in a diffused and disseminated condition in the thinly dispersed sediments, will migrate into collecting rocks, particularly sandstones and siltstones. Therefore one cannot ignore the role played by the amount and thickness of argillaceous beds in the distribution of oil in natural reservoirs. If this concept is correct, in the Apsheron peninsula, one should observe a definite connection between the relationship of clay and sand rocks in the section of the producing series and the amount of oil distributed in it. Such a connection will be supplementary confirmation of the assumption made above regarding a genetic connection between oil and the producing series itself.

We have compared data on the quantities of oil not only in suites or horizons of a single origin in various oil deposits of the Apsheron peninsula, but also in various stratigraphic units within the same deposit. We have also compared horizons or suites with interbedded sandstone whose effective or total thickness is identical. Such comparison shows that where the thicknesses of the sand in a certain horizon or suite are identical, as the general thickness increases by growth of the argillaceous layers, the amount of oil in this horizon or suite as a whole also increases. This increase clearly cannot continue without end; consequently, there is some sort of limit above which increase in the clay content does not involve a growth in the amount of oil in the suite or horizon. We must establish the degree of connection between the amount of oil and the amount of clay in the section. One criterion that allows the establishment of such a connection can be the specific amount of oil per cubic meter of volume of the whole horizon or suite. The distribution of specific amounts of oil with degrees of argillaceousness shows the following: with an increase in the amount of clay in the section up to 40 percent the specific amount of oil increases, and thereafter sharply decreases. The limits in the specific quantities of oil in the oil-bearing horizons or suites of the producing series of the Apsheron peninsula are, on the average 0.03 thousand tons minimum, 1.2 thousand tons maximum.

The amount of clay in the section also influences the degree of filling up the horizon or suite with oil. We have expressed this degree as a coefficient of filling that characterizes the relationship of effective to total thickness of the sands in the horizon or suite. As the clay in the section increases, the coefficient increases. Characteristically, this increase begins at the 40-49 percent interval of argillaceousness, that is, when in association with the growth of clay the specific amount of oil diminishes. It must be noted that the amount of this coefficient in the deposits of

the western part of the Apsheron peninsula is in even units throughout almost all horizons; here all the sandy layers are saturated with oil. In the indicated regions, the complete saturation of the sandy interbeds of various horizons or suites is determined by this very increase in the clay of the section.

In comparing the data on the amount of clay in the section with specific or general quantity of oil in some horizons, one observes an inverse relationship between them. This question remains as yet unexplained and requires further work.

In conclusion, we must note that the amount of clay in the section is only one of numerous factors on which depends the quantity of oil in natural reservoirs. The influence of other, no less important factors could quite possibly conceal the significance of the amount of clay in the section, in uncovering the causes determining the distribution of oil. Therefore further detailed and many sided investigations of regularities in the distribution of oil, gas, and water, in relation to the complex of geologic conditions, should reveal other factors, a knowledge of which will allow us to proceed to complete solution of such questions as the formation of oil and gas deposits in the Apsheron peninsula.

Kartsev, A. A., CENOTYPIC AND PALEOTYPIC OILS. Differences in specific weight, sulfur, and paraffin content, and so forth between Paleozoic, Mesozoic, and Cenozoic oils have been established on the basis of masses of statistical data. The hydrocarbon content of oils is of fundamental importance. Differences in the hydrocarbon content of Cenozoic and Paleozoic oils were pointed out long ago (Hoeffer), but without sufficient factual foundation.

From data in the analysis of 65 oils, plotted on a diagram, it has been established that all the oils of the Paleozoic contain no less than 30 percent of alkanes on distillation, whereas those of the Mesozoic and Cenozoic may contain both less and more than this amount. The enumerated average contents of different classes of hydrocarbons in the distillation of 65 oils show that the cyclical nature of the oils decreases from the Cenozoic to the Mesozoic and from the latter to the Paleozoic.

From data in the analysis of 45 foreign benzines, plotted on a diagram, it has been established that all Paleozoic benzines contain no less than 50 percent of alkanes, while the amount in Cenozoic benzines is not higher than 55 percent. The enumerated average contents of different classes of hydrocarbons in the benzines of 45 foreign oils show that the relation of cyclanes to alkanes in the benzines decreases from the Cenozoic to the Paleozoic.

Consideration of the data on the foreign benzines confirms and supplements the conclusions that were drawn from data on the distillation of oils primarily from the U. S. S. R. From data on 25 benzines there emerges a growth in the content of normal alkanes, and in their relation to isoalkanes, from the Cenozoic to the Paleozoic.

It has been shown that oils containing less than 30 percent of alkanes in their distillates and less than 50 percent in their benzines, which are characteristic of the Cenozoic, are not found in the Paleozoic and may be designated "cenotypic." Oils containing more than 30 percent alkanes in their distillates and more than 50 percent in their benzines are characteristic of the Paleozoic and may be called "paleotypic," although they are also found in younger systems. The "paleotypic" characters of all Paleozoic oils proves their Paleozoic origin and, consequently, that the formation of oil was already going on in the Paleozoic.